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Progress Report: Hydrologic Research at the Big Sky Mine

PROGRESS REPORT

HYDROLOGIC RESEARCH AT THE BIG SKY MINE[1/]

I. COALBANK COULEE HYDROLOGY

II. RESERVOIR FEASIBILITY IN SPOIL RECLAMATION

by

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July 1977

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ACKNOWLEDGEMENT

The authors thank the Big Sky Mine reclamation staff, Mr. Alten Grandt, St. Louis office, Mr. Gene Tuma, Colstrip office, and Mr. George Robinson, Denver office, for their excellent cooperation during these studies. A special acknowledgement is in order to Mr. Larry Fox, Big Sky Mine supervisor, for use of his personal time and equipment during construction phases of this research.

The authors thank Dr. Richard Meyn, former M.A.E.S. watershed scientist for his help in initial planning and manuscript preparation on this project.

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INTRODUCTION

The Big Sky Mine, owned and operated by the Peabody Coal Company, is located in southern Rosebud County about 9.6 km south of the town of Colstrip, Montana (Figure 1). The mining operation will extract coal from portions of Sections 13, 14, 15, 21, 22, and 23, within Coalbank and Miller coulees drainage basin, tributaries to Rosebud Creek. The area has considerable relief (Figure 2), ranging between 915 and 1065 meters above sea level. Local climate is characterized as continental, warm in summer, cold in winter. Average annual precipitation is 40.1 cm (U.S. Dept. of Commerce).

The Montana Agricultural Experiment Station has been conducting several hydrological studies in the Colstrip area (Arnold and Dollhopf, 1977; Dollhopf and Meyn, 1975). This interim report discusses two hydrological studies presently being conducted at the Big Sky Mine, Colstrip, Montana. In the Coalbank Coulee watershed (Figure 1), which encompasses about 1200 hectares, the Experiment Station is evaluating the present state of the ground water, surface water, and soil water resources. Approximately 325 hectares in this region will be strip mined during the next several decades. Particular attention has focused on a 90 hectare alfalfa field in the lower Coalbank Coulee basin, portions of which are subirrigated. The basis of concern is that mining of the sub-bituminum coal from upper portions of the watershed may interrupt the ground-water regime, resulting in a water table drop sufficient to reduce production in alfalfa fields in downstream alluvium. Such concerns stem from a larger, more general theme regarding conflicts between western strip

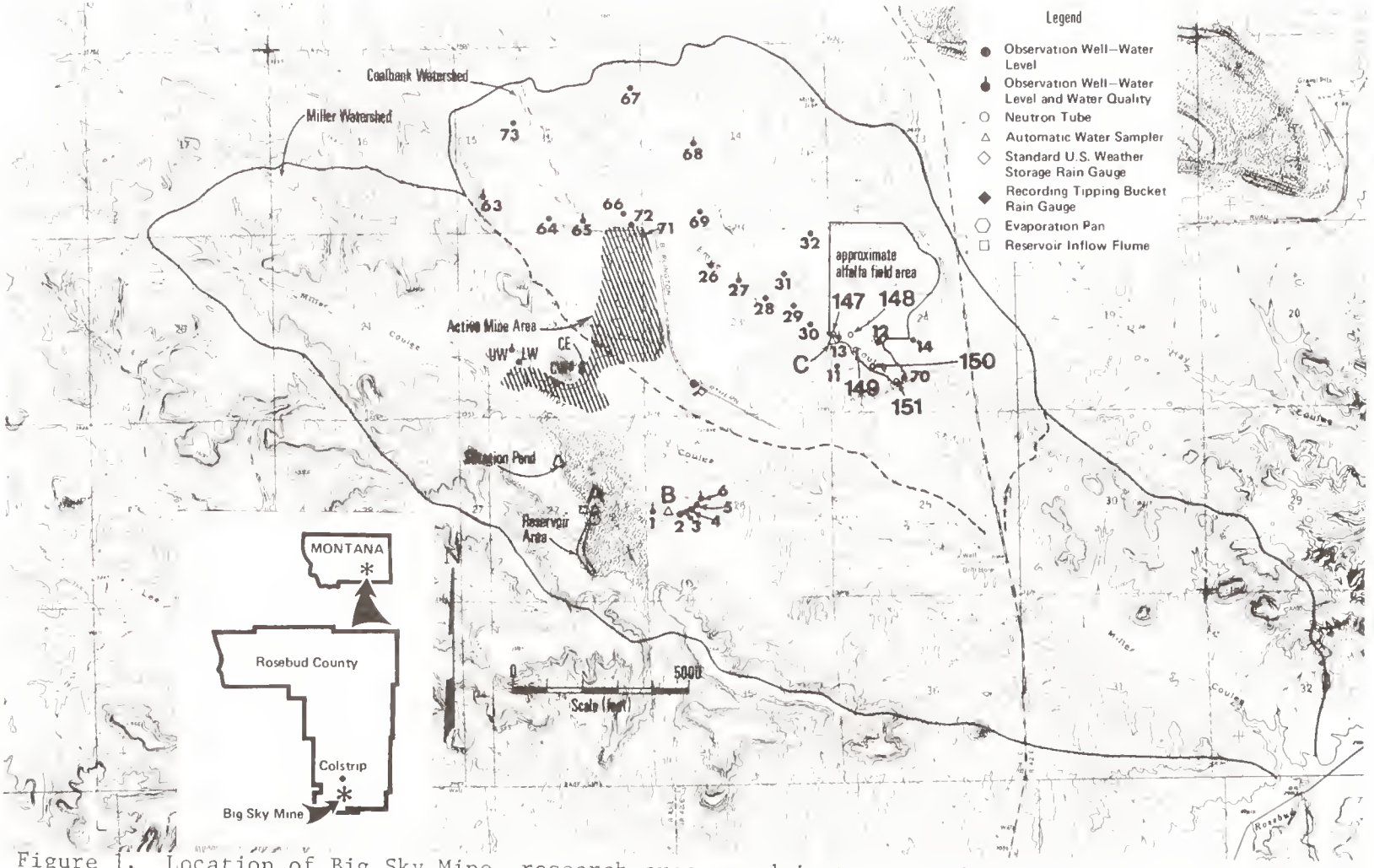

Figure 1. Location of Big Sky Mine, research areas, and instrumentation installations, (February, 1977)

Figure 2. Upper and Lower Coalbank Coulee, respectively. Colstrip, Montana.

mining and agriculture. This report presents a quantitative description of the existing hydrological characteristics in Coalbank Coulee.

The second study discussed in this report pertains to the feasibility of including a reservoir in spoil material as part of the Big Sky Mine reclamation plan. Present State of Montana reclamation guidelines do not encourage such a development, largely due to the unknown effects of such an impoundment upon the environment and due to concern that a semiarid climate may not sustain a viable reservoir on spoils.

In 1975 the Big Sky Mine was granted temporary permission to construct a reservoir within recontoured spoils under condition that the hydrological characteristics of the reservoir be monitored for a number of years. At the end of this research period the State shall review the feasibility of this reservoir on the basis of research results. The Miller Coulee watershed encompasses about 2145 hectares and about half of this surface drainage area is planned to be diverted into the reservoir (Figure 1). The intent is to utilize intermittent surface flows from the Miller watershed to sustain the reservoir. This report presents the first year hydrologic data.

COALBANK COULEE HYDROLOGY

Surface Hydrology

Morphology

The Coalbank Coulee sub-basin comprises an area of approximately 1200 hectares. The topography consists mostly of gently sloping, semiarid rangeland. It lies to the north but adjacent to the Miller Coulee sub-basin (Figure 1). The drainage channel at the confluence of Miller and Coalbank Coulee sub-basins is an intermittently flowing channel. Coalbank Coulee has numerous, but intermittent, third, second, and first order channels entering it.

The elevation differential of the main drainage channel is about 155 meters. The highest point is roughly 1100 meters above sea level (a.s.l.) while the lowest point at the injunction with Miller Coulee is about 940 meters a.s.l. The total channel length is approximately 5940 meters, and the average channel gradient is 2.6 percent. Approximately 100 meters of the main channel have been disturbed by mining. The average gradient along the channel above the mined area is 6 percent; in contrast, the average gradient below the mine averages 1.3 percent (Figure 1).

Drainage from Coalbank Coulee is to Miller Coulee which in turn flows in a southerly direction to Rosebud Creek. Rosebud Creek turns north and flows into the Yellowstone River near Forsyth, Montana, approximately 56 km from Coalbank Coulee. The uppermost boundary of Coalbank Coulee is well defined by a rim of weather resistant clinker and sandstone. Sheer cliffs can be found at this point. Beyond the rim of cliffs or bluffs is a plateau of small areal extent.

Vegetation

The vegetation of the Coalbank Coulee sub-basin consists of primarily native bunchgrasses, shrubs, forbs, and trees. The gently sloping and lower portion of the basin is predominantly a grassland type with occasional trees. Cottonwoods (*Populus deltoides*) are found in and along the lower drainage channel where the soil is moist. The upper portion of the basin consists of grasslands interspersed with a pine woodlands type. Ponderosa pine (*Pinus ponderosa*) and juniper (*Juniperus* spp.) are found on the rocky upland slopes and on the plateau area.

Differentiation between vegetative species growing within the drainage channel and upon the adjacent slopes reflects past grazing management practices (Dr. D.E. Ryerson, Montana State University, personal communication, 1975). No severe climatic changes have occurred within the past 50 years which could explain the vegetative development that has occurred. Colonies of prairie sandreed grass (*Calamolvilfa longifolia*), a warm season grass, have spread from the upper ends of the drainage channel, down the sides, and onto the channel bottom of Coalbank Coulee. This species spreads primarily by rhizomes (subterranean stems) and requires many years (possibly decades) for such expansion to take place. Such growth would be unlikely with active channel erosion. In a similar manner, colonies of little bluestem (*Schizachrium scoparium*) have spread to a distance of 100 meters or more into densely vegetated rangeland. Such encroachment does not readily occur with grazing or with land disturbance. Thus, the vegetation of Coalbank Coulee provides a basis for estimating the history of land use, the level of land disturbance, and the period of time since major surface drainage activity has occurred.

Channel Morphology

The channel areas below the mined site and the adjacent basin slopes are well stabilized with a dense cover of vegetation. There are no signs of active erosion or massive slippage. The stability of the drainage channel is considered excellent when compared to other drainage channels in the local area and when considering the limitations of a semiarid climate on plant growth.

The channel of Coalbank Coulee from the mined area to the confluence with Miller Coulee shows no visible evidence of active or erosive flow in 10 or more years, possibly 50 or more years. There are no deposits of plant and soil debris as one would find in an active, but intermittent, drainage channel. There are no visible signs of scouring. The channel below the mine is apparently being slowly raised by silt deposition from small surface flows during the spring. This conclusion is supported by an average 1.3 percent gradient, and in places a reverse gradient, in the channel below the mine as compared to a general basin gradient of 2.6 percent at the upper slope position.

Root Zone Hydrology

In Montana there are about 202,350 hectares (500,000 acres) of dryland alfalfa production. Most of this acreage is used for hay production, but approximately 40,500 hectares are used for seed production. Economic value of alfalfa grown in Montana for seed can range between $100 and $1,000 per acre depending upon yield and market price. Most of the root biomass of dryland alfalfa is found within 3 m of the surface and the viable roots are found within 1.4 m of the surface.[1] Occasional reports (i.e., Hughes, et.al., 1962), have indicated alfalfa rooting depths of 9 m, or, in some rare instances, over 60 m where a root has followed a crack in an attempt to seek soil water. However, in Montana it has been shown that dryland alfalfa will generally root in the surface 3 m of soil and extract its water requirements within the upper 5 m of soil.[2]

In Coalbank Coulee, the 90 hectare alfalfa field, owned by Mr. Snider, a local Colstrip rancher, has been grown for seed in recent years. In order for the alfalfa to produce seed it must slow or stop its vegetation production and progress into a reproductive state. This change is triggered by a soil water stress which, for maximum seed production, would ideally occur in late June. Harvesting of the seed would generally take place in mid-August.

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[1] Personal communication with Dr. Raymond Ditterline, forage researcher and Asst. Professor, Plant & Soils Dept., Montana State University.

[2/] Unpublished data from salt seep research in the Highwood Bench area of Montana by Dr. P.L. Brown, Soil Scientist, Agriculture Research Service, Highwood, Montana.

Variation from this phenological scheme can decrease seed production and, if the plant water stress period is late, then seed development may extend into September when freezing becomes damaging. Therefore the soil water characteristics of this field are very important and are discussed in this section.

Methods

Neutron access tubes were installed in or near the lower part of the alfalfa field (Figure 1) next to Coalbank Coulee during December of 1974 to monitor the changes in soil water content as a function of time. The neutron scattering method was chosen for its ability to nondestructively sample a given point at frequent intervals.

The reader is referred to Schultz (1965) for detail on the theory of the neutron method as well as its applicability in estimating water content of the unsaturated zone. In brief, a radioactive source (contained in a probe) is lowered into the ground. High speed neutrons are emitted from the source into the adjacent soil. Upon striking water or other hydrogenous materials, these neutrons are slowed down and become low speed neutrons. Some of these low speed neutrons are deflected and make their way back to the probe where a gas-filled, electronically-amplified detector counts them as a function of time. The percent of water in the soil is then determined by comparison of the number of slow neutrons counted (field count) as compared to a reference of known water content (shield count). For example, a neutron probe reading may indicate a 50 percent moisture content. A soil with volumetric moisture percentage of 50 percent would then equal 15 cm of water per 30 cm of soil.

Five neutron access tubes were installed on a transect extending from native range, across Snider's alfalfa field, to a point on disturbed range (Figure 1). The disturbed rangeland site is a result of construction activity to build a landfill railroad pass over Coalbank Coulee (Figure 1). Measurements began in January 1975, and were taken subsequently in monthly intervals. Identification, location and approximate depth of installation of neutron probe access tubes in Coalbank Coulee are listed in Table 1.

Table 1. Neutron probe access tubes in the lower Coalbank Coulee region, 1976.

Tube Number (old)	Tube Number (new)	Maximum Depth (cm)	Maximum Depth (inches)	Location
13	147	165	65	Disturbed range
14	148	255	100	Alfalfa field
15	149	255	100	Alfalfa field
16	150	255	100	Alfalfa field
17	151	315	124	Native range

Soil water content data alone can leave some question as to whether a determination, i.e. at 40%, is at near saturation (0 bars), or near field capacity (≈.3 bars), or near the wilting point (≈15 bars). In order to substantiate the interpretation of water content data, they are best presented with the desorption characteristics of the soil material, which indicate the water content percentage at various soil water potentials, i.e. 0.0 bars, 0.3 bars, and 15 bars. Soil water desorption characteristics were determined at the 0.0, 0.1, 0.3, and 15 atmosphere tension levels using a standard pressure plate apparatus. This analysis was performed on soil material from the 0-90 cm depths immediately adjacent to neutron tubes in the alfalfa field, in rangeland, and in disturbed rangeland.

Results and Discussion

Profiles of percent water in the soil as a function of depth and time shown in Figures 3 and 4 tell much about the hydrology of the unsaturated soil zone and about soil water-plant relationships. Soil water, like all bodies in nature, can contain energy in different quantities and forms. It is these different states of energy which direct the flow of soil water and dictate the ability of plants to absorb water from the soil. A detailed discussion of these energy factors is complex and not necessary for this report. Let it suffice to say that the soil water potential is the criterion for this energy and is composed largely of the gravitational, matric, and osmotic potentials (Equation 1).

$$\Psi_t = \Psi_g + \Psi_m + \Psi_o \qquad \text{Eq. 1}$$

where Ψ_t = total soil water potential

Ψ_g = gravitational potential; attraction of a body towards the earth's center

Ψ_m = matric potential; capillary and adsorptive forces due to the soil matrix

Ψ_o = osmotic potential; water solutes affect its potential energy

In order for a plant root to absorb water from the soil, it must have an energy, or plant potential (Ψ_p), greater than the soil water potential (Ψ_t). Even though the plant attains a $\Psi_p > \Psi_t$, it may wilt if its roots cannot physically conduct sufficient water to meet biological and transpirational demands. Alfalfa under this kind of stress could be triggered into a reproductive state from a vegetative growth state.

Soil and plant scientists have related the soil water potential to plant performance by use of several generalized terms. The authors realize

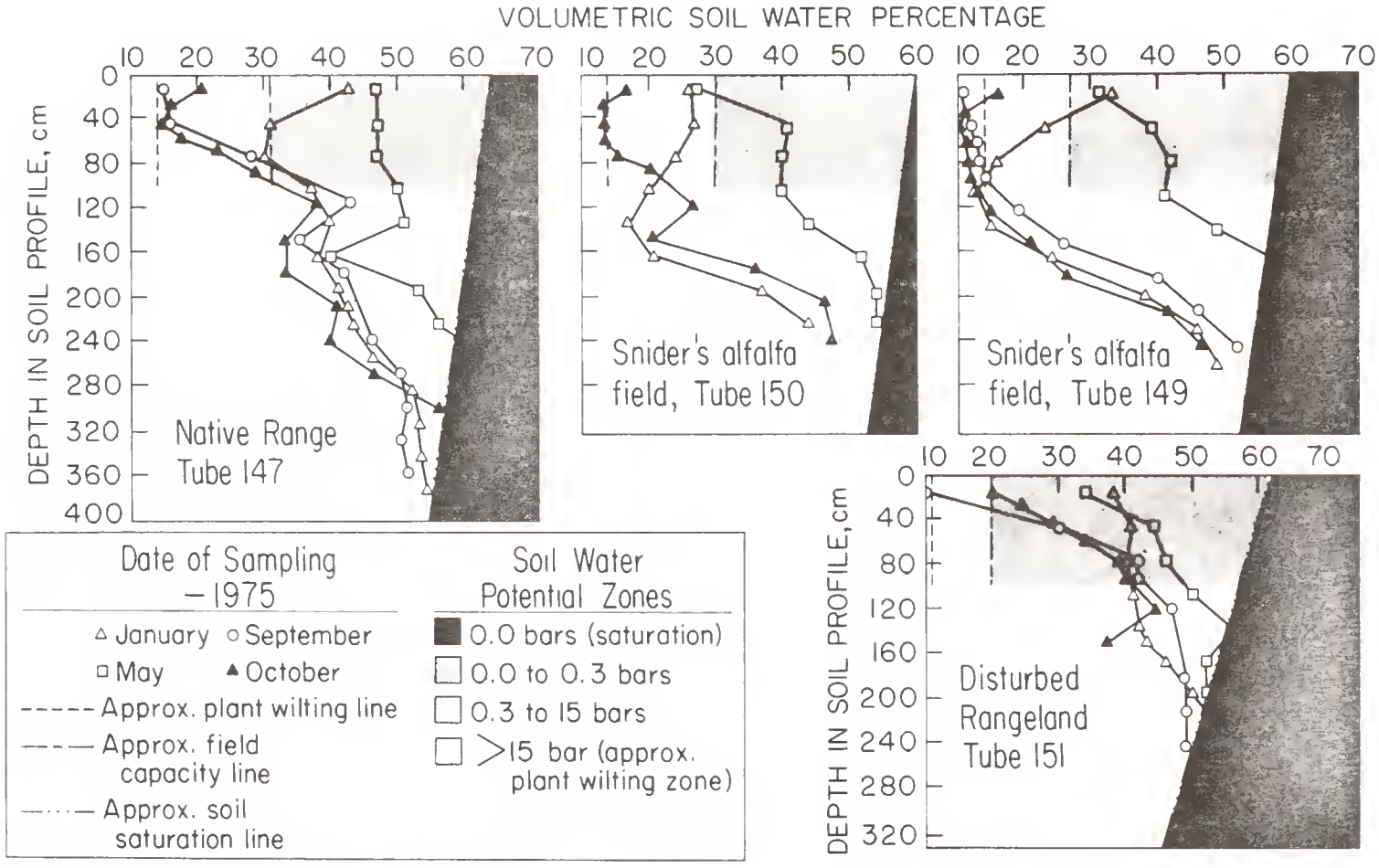

Figure 3. Changes in soil profile water content over time in the lower Coalbank Coulee region during 1975.

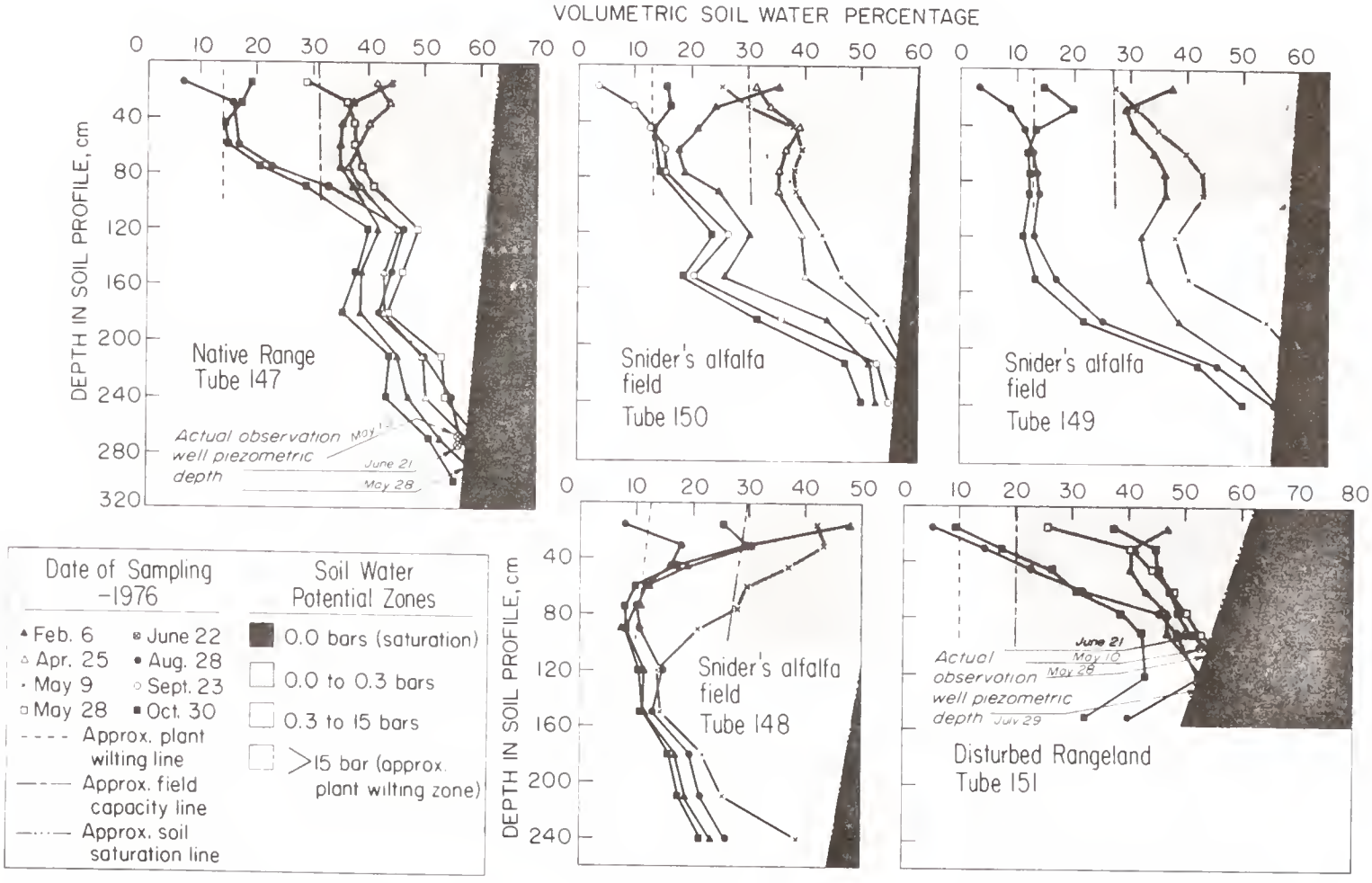

Figure 4. Changes in soil profile water content over time in the lower Coalbank Coulee region during 1976.

the technical limitations of these terms, but also recognize their usefulness in describing these data to the reader. Figures 3 and 4, which show the alfalfa field soil water characteristics, present soil water potential terminology.

The approximate plant wilting, field capacity and soil saturation lines shown in Figures 3 and 4 define soil water potential zones, which indicate how much water the soil material will contain at soil water potentials of 15.0, 0.3 and 0.0 bars. Saturation (0.0 bars) is that point at which a soil will no longer absorb water, meaning all the air spaces in the soil matrix are filled with water. When a soil has been near saturation and then the gravitational water has been drained away, it is said to be at field capacity (0.3 bars). If we were to use many types of plants and determine at what soil water potential they will permanently wilt, their accumulated average would be near 15 bars, and the percentage of water in the soil when this permanent wilting occurs is the wilting point.

The boundary soil water potential lines in Figures 3 and 4 were determined from soil desorption work in the laboratory (Appendix A). It should be noted that this technique determines the matric potential (Ψ_m) component of the total potential (Ψ_t), discussed previously in Equation 1, which is a close approximation of Ψ_t, since the osmotic potential (Ψ_o) and gravitation potential (Ψ_g) would be small in comparison.

The soil water profile curves shown in Figure 3 are characteristic of the 1975 hydrologic year. The percent water versus depth profiles in January, May, September and October have been graphed, and September and October represent the driest time of the year while May represents the wettest, and January represents an intermediate soil water level. The

change which occurs between January and May approximates the bulk of soil water recharge. The change between May and October represents the major portion of the soil water depletion. Other months, if graphed, would result in lines at intermediate positions.

The profile curves shown in Figure 4 are characteristic of the 1976 hydrologic year. The percent water versus depth profiles in February, April, May, June, August, September and October have been graphed, and August, September, and October represent the driest time of the year, while April, May, and June represent the wettest, and February represents an intermediate soil water level. The change which occurs between November, 1975 and May, 1976 approximates the bulk of the net soil water recharge in the subsoil and substratum. The change between May and October represents the major portion of the soil water depletion.

The soil water content throughout each soil profile during May was above field capacity (Figures 3 and 4). The deeper substratum depths (150 cm or deeper) in most profiles remained above field capacity throughout both years. In most instances, the lower substratum approaches saturation and appreciable amounts of soil water were percolating through the soil at this time. Depth to ground water was approximately 270-330 cm near the native range site and became less deep going downslope towards the disturbed rangeland site where the ground-water level was near 120-180 cm below ground surface (Figure 4). Depth to ground water near the native range was determined from water level data collected from well #13 located a few feet downslope from the neutron tube. The water levels near the disturbed rangeland site were determined from measurements in well #70 located about 20 meters downslope from the

neutron tube. It is likely that some contribution to the ground water from precipitation occurred between the January to May period.

The importance of ground water on the hydrology of the unsaturated zone in or near the lower profile of the alfalfa field is further emphasized by noting the soil profile recharge which occurred between January and the May-June period in 1975 and between the November 1975 and the April-May 1976 period (Figures 3 and 4). The total water recharge which occurs between any two dates for any one tube is the net difference of the profile soil water content between those two dates, plus any evapotranspiration which may have occurred between those dates. The two different dates for determining annual recharge are defined to be when the soil profile is most dry in the fall and most wet in the spring (Appendix B and C).

Monthly evapotranspiration values were calculated using the Thornthwaite method. Stanhills' 1961 comparison of seven empirical methods used to calculate potential evapotranspiration (PE) under arid conditions against lysimeter measurements showed that the Thornthwaite method was second only to the Penman method. These PE calculations are based upon average monthly temperatures recorded from October 1975 through September 1976 at the Peabody Big Sky Mine by ECS* monitoring equipment. Evapotranspiration for the 1975 and 1976 recharge periods was 13.4 and 10.5 cm, respectively.

In 1975, estimated recharge from 14 January to 10 June (Appendix B) for the native range, two alfalfa fields and the disturbed rangeland profiles was 21.4, 60.4, 61.9, and 53.4 cm, respectively. In 1976, estimated recharge from 30 October 1975 through 28 May, 1976 (Appendix B & C) for the native

*Ecological Consulting Service, Helena, Montana

range, three alfalfa fields and the disturbed rangeland profiles was 50.6, 39.0, 50.7, 52.8 and 41.1 cm, respectively. The variation in recharge quantities between the five tubes may be attributed to the differences in tube depth (Table 1), soil texture, water holding capacities (Appendix A) and/or depth to ground water.

In all instances, the quantity of recharge far exceeded possible inputs from precipitation during the period. In 1976, 23 cm of precipitation were received during the recharge period (Table 3). Using storage gauges in the Colstrip area it was determined that 18 cm of precipitation was received during the recharge period in 1975. Therefore, the estimated percent of average annual recharge supplied by ground water among the five sites in the lower part of the alfalfa field was 63% in 1975 and 51% in 1976.

In conclusion, there was no significant net change in soil water content of Coalbank Coulee during 1975 and 1976. Second, the contribution of soil water in the alfalfa root zone from the ground water is quite significant. During 1975 and 1976, approximately 57% of the total recharge of soil water in the lower part of the alfalfa field was from ground water. The remaining 43% was from precipitation.

An important point needs to be made at this time. These neutron probe data only apply to the lower part of the alfalfa field adjacent to Coalbank Coulee. Depth to ground water in these areas is usually less than 6 meters. In the northern portion of the field, where depth to ground water exceeds 18 meters, it is very likely that the ground water contributes little water to the alfalfa root zone. This needs to be researched and plans are to install neutron access tubes and an observation well in this area during spring 1977.

Ground-Water Hydrology

Introduction

Disruption of aquifers and the potential for alteration of the ground-water system are occurrences commonly associated with strip mining of coal in southeastern Montana. However, the significance and the extent of environmental changes caused by this mining are not well understood. The principal objectives of the ground-water monitoring studies conducted by the Montana Agricultural Experiment Station are: (1) to describe the baseline hydrogeologic characteristics of the Big Sky Mine area with emphasis on Coalbank Coulee and, (2) to evaluate the effects, if any, that mining is likely to have on the depth, flow and quality of ground water in Sniders alfalfa field.

Hydrogeologic Setting

Central Rosebud County together with adjacent parts of eastern Montana, Wyoming and the Dakotas is known as the Fort Union coal region (USDI, 1973). Coal beds of economic importance in the Colstrip area are confined to the Tongue River member of the Fort Union Formation, and are distributed at irregular intervals throughout the member (Figure 5).

The Rosebud is the thickest and most valuable coal in central Rosebud County. At the Big Sky Mine, the Rosebud coal seam generally has a thickness of 20 to 30 feet and may be overlain by as much as 310 feet of interbedded sandstone and shale, friable sandstone and minor amounts of sandy claystone (USDI, 1973). Baked and fused sandstone and shale formed by the burning of adjacent coal beds are present throughout the mine area. Underlying the Rosebud is up to 30 feet of gray shale and

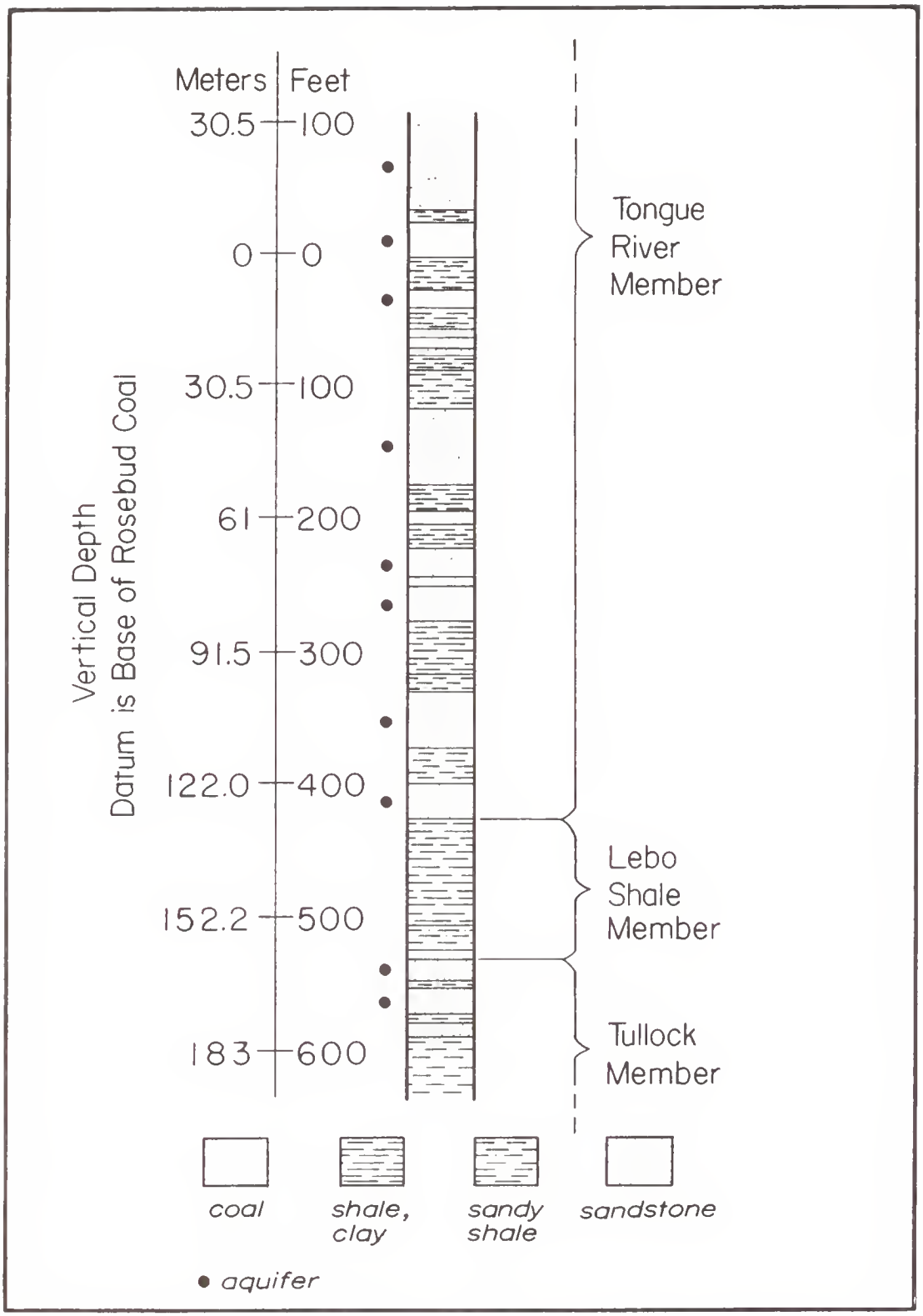

Figure 5. Generalized stratigraphic column of part of the Fort Union Formation near Colstrip, southeastern Montana (from Van Voast and Hedges, 1976).

fine grained sandstone which overlie the McKay coal (USDI, 1973). The McKay, in turn, is most likely underlain by alternating sandy shale and sandstone.

The Rosebud and McKay coals in the Big Sky Mine area are gently dipping deposits. As such, their aerial extent is controlled not only by the depositioned environment and subsequent structural changes but also by local topography. Mineable deposits are restricted for the most part to the northwestern half of Coalbank Coulee and a segment of the central part of Miller Coulee. Near surface deposits in the lower Coalbank and Miller Coulee basins are stratigraphically below the Rosebud and McKay coals and, in some places, are overlain by colluvial material (Van Voast, personal communication, 1977).

Monitoring Program

Several series of observation wells have been installed at the Big Sky Mine by the Montana Agricultural Experiment Station to gain an understanding of the hydrogeologic characteristics and to provide a means for monitoring ground-water movement and quality (Figure 1). Wells 11, 13, 26, 27, 28, 29, 30 and 70 provide information about ground-water conditions in alluvium along Coalbank Coulee. Water in the unmined Rosebud coal in northern Coalbank Coulee is monitored with observation wells 63, 64, 65, 66, 67 and 68. Water level fluctuations in Rosebud overburden are monitored with well 73 in the extreme northern part of Coalbank Coulee. Wells 69, 32, 31, 14 and 12 are completed in the sands and sandstones stratigraphically below the Rosebud and McKay coals in central and lower Coalbank Coulee. Additional ground-water monitoring is also being conducted by the Montana Bureau of Mines and Geology.

Aquifer Characteristics

Subsurface water-bearing zones at the Big Sky Mine emphasized during the present investigations were those suspected to be most directly affected by mining activities. These zones, determined with the aid of drillers logs (Appendix D), are: (1) the alluvial deposits adjacent to Coalbank Coulee; (2) the relatively shallow sands and sandstones stratigraphically below the Rosebud and McKay coals in central and lower Coalbank Coulee; and, (3) the Rosebud coal.

Water level fluctuations in wells in Coalbank Coulee are plotted in Figures 6 and 7. The raw data are presented in Appendix E. Miller Coulee hydrologic data are briefly discussed in Appendix F. The hydrographs for the alluvial wells and for wells in sands and sandstones in central and lower Coalbank Coulee (Figure 6) indicate that a small amount of recharge occurred during the spring of 1976. Few if any major changes are illustrated in the Rosebud well hydrographs (Figure 7).

During November, 1976, short-term pumping tests were conducted on several of the wells in Coalbank Coulee. The tests were conducted with a submersible pump. Each well was pumped for about 30 minutes or until an apparent equilibrium condition was attained. An adjustable hose nozzle was used to keep pump pressure and discharge relatively constant. Discharge was calculated using a 5 gallon bucket and a stop watch. Specific capacities were determined and are shown in Table 2. In addition, recovery measurements were made in the pumped well.

Transmissivity values were calculated from the recovery measurements (Johnson, 1972) and from specific capacity data (Theis, C.V. and others, 1963). Transmissivity is an indication of the ability of an aquifer to

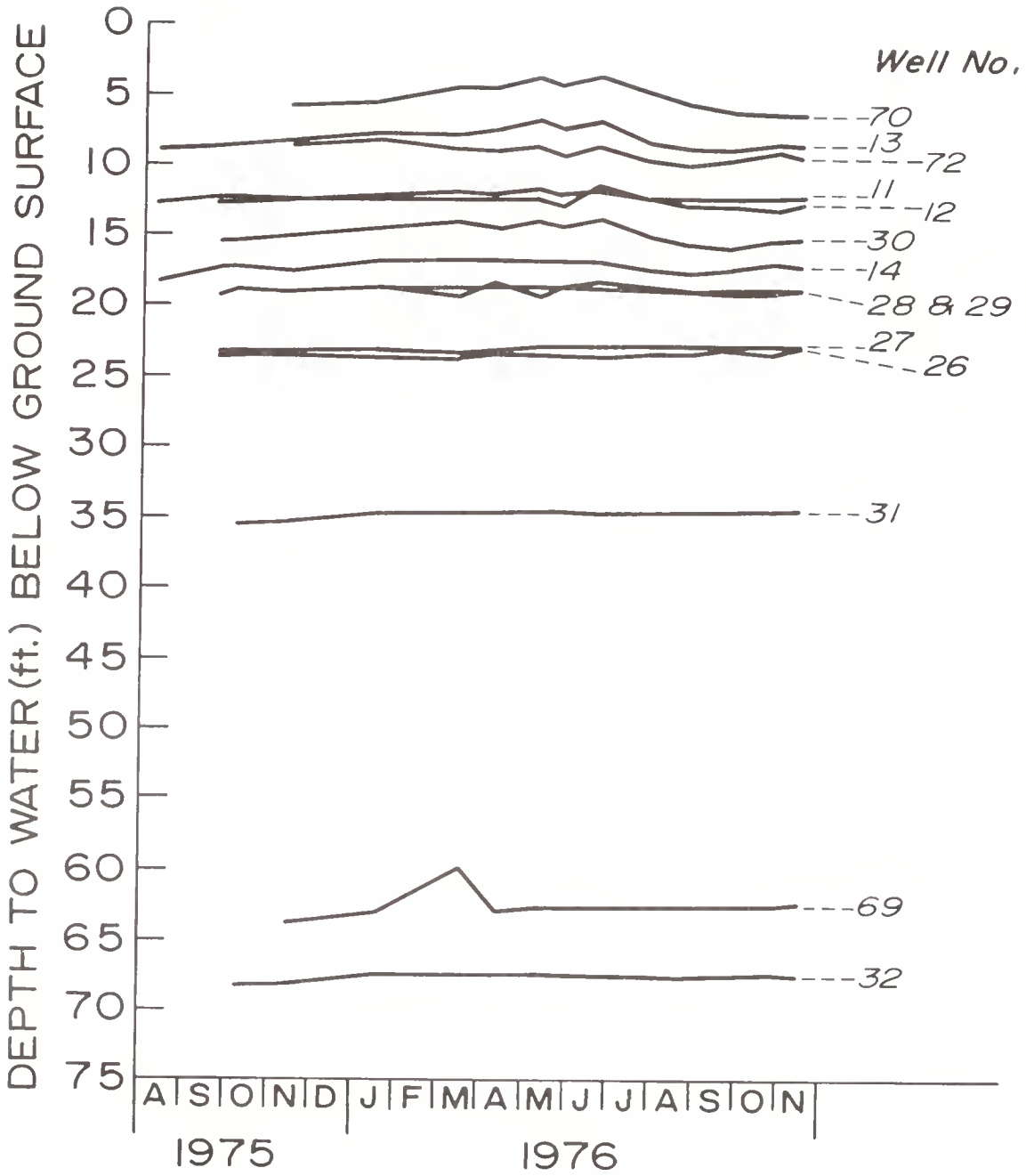

Figure 6. Water level fluctuation in observation wells 11, 12, 13, 14, 26, 27, 28, 29, 30, 31, 32, 69, and 70 in lower Coalbank Coulee watershed.

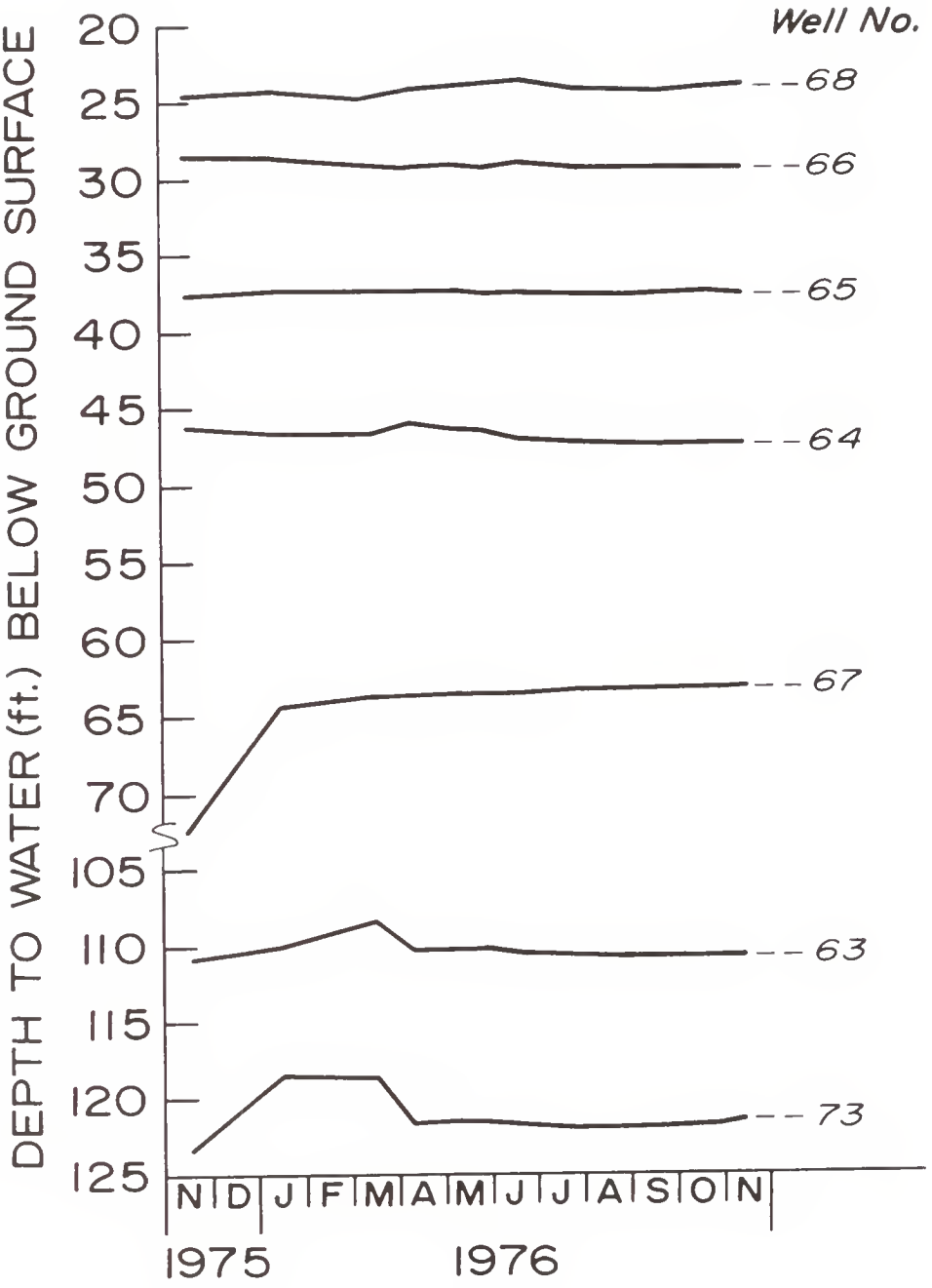

Figure 7. Water level fluctuation in observation wells 63, 64, 65, 66, 67, 68, and 73 in upper Coalbank Coulee watershed.

Table 2. Hydrologic characteristics of subsurface water-bearing zones in lower Coalbank Coulee of the Peabody Big Sky Mine.

Well No.	11	13	26	29
Well Depth (m)	6.28	5.70	12.04	7.07
Test Date	11/11/76	11/11/76	11/14/76	11/12/76
Average Pumping Rate (m^3/min)	.0036	.0207	.0148	.0193
Maximum Drawdown (m)	1.62	1.67	3.16	0.55
Specific Capacity (m^2/min)	.0023	.0125	.0046	.0353
Calculated Transmissivity (T)	--	--	--	--
Recovery vs +/+' (m^2/day) (1)	0.6	45	7.5	40
Specific Capacity (m^2/day) (2)	4.6	25	9.3	71
Zone Tested	alluvium	alluvium	sandstone of Fort Union	sands of Fort Union

(1) Johnson, U.O.P., 1972
(2) Theis, C.V., and others, 1963

transmit water. As can be seen in Table 2, there was a wide range of transmissivity values. Reasons for the broad range in the alluvial deposits and in sands and sandstones of the Fort Union may include well construction and textural changes within the formation. Pumping was also done in several wells which monitor the Rosebud coal seam; however, the Rosebud seam was not sealed off during well installations and the test data, therefore, were inconclusive as to quantitative hydrologic characteristics of the coal. It was apparent, however, that yields varied significantly between these wells.

An overall objective of the studies in Coalbank Coulee was to utilize information gained in the monitoring programs to evaluate the effects of mining on alfalfa production at Sniders field in the lower Coalbank Coulee basin. Evaluation of water level fluctuations in the surrounding observation wells (32, 31, 13 and 12) (Figure 6) suggests that the water table in the area has not been influenced by mining activities. In fact, none of the wells below the present mining activity in Coalbank Coulee have shown a net decline in

levels since the monitoring program began. Continued observation and evaluation of water levels and water quality from observation wells surrounding the alfalfa field, together with soil moisture data from neutron probe studies, should provide sufficient information to predict potential impacts of mining on the alfalfa field in the future.

Summary

1) Evaluation of water level fluctuation in observation wells in lower Coalbank Coulee suggests that the water table in the area has not been influenced by mining activities.
2) As much as 57 percent of the water measured in the alfalfa crop root zone near Coalbank Coulee in the lower part of the alfalfa field came from the deeper ground-water resource by capillary rise. The remainder of the soil water came from precipitation.
3) Generally, the surface 1.5 m of soil in the alfalfa field did not receive water by capillary rise phenomena, and dried out significantly during the summer. Drying of this surface soil triggers the alfalfa into a reproductive state from a vegetative production state. This was necessary for seed production, the intended use of the crop.
4) The greatest biomass of roots and those which are most viable are found in the surface 1.5 m of soil. Deeper roots are present, but they contribute less significantly to the plant development process.
5) Deep roots extending into wet soil material may become important in sustaining plant life during drought years.
6) If alfalfa seed production continues to be the primary objective in Sniders field, a drop in water table elevation should have little, if any, effect on yield during near normal precipitation years.
7) If the field goes into alfalfa hay production, a drop in water table elevation could have a more adverse effect.

RESERVOIR FEASIBILITY IN SPOIL RECLAMATION

RESERVOIR FEASIBILITY IN SPOIL RECLAMATION

Reservoir History

As stated in the introduction, the State of Montana does not encourage the development of a water impoundment on spoils as part of a long term reclamation plan. It is felt that reservoirs could have an adverse effect upon the water resources of the area. There is also some doubt as to whether a semiarid climate will sustain a viable reservoir. Opposing viewpoints suggest that such a reservoir could be used by livestock and wildlife, and could provide an aesthetic place for human recreation including fishing, swimming, and boating. Also, there is an economic savings in reclamation costs since a highwall area could be incorporated into the reservoir planning and construction thus minimizing major recontouring of spoils.

Mining activity at the Peabody Big Sky Mine began in 1969. Five years later, a portion of the spoils was shaped to contain about an 8 hectare (20 acre) reservoir (Figure 8). The State agreed to permit a temporary reservoir, for a period of time, suitable for research concerning the reservoir hydrology.

The plan called for diversion of Miller Coulee into the reservoir. About half of this 2145 hectare (5000 acre) watershed will be diverted with the intent that intermittent surface flows will fill and sustain the reservoir. During the first year of research this plan was complicated by a necessary mining maneuver directly involving Miller Coulee upslope from the reservoir location. These mining activities reduced the effective area of the Miller watershed, which drained into the reservoir, to only 80 hectares (200 acres). The study was further complicated by an excessive

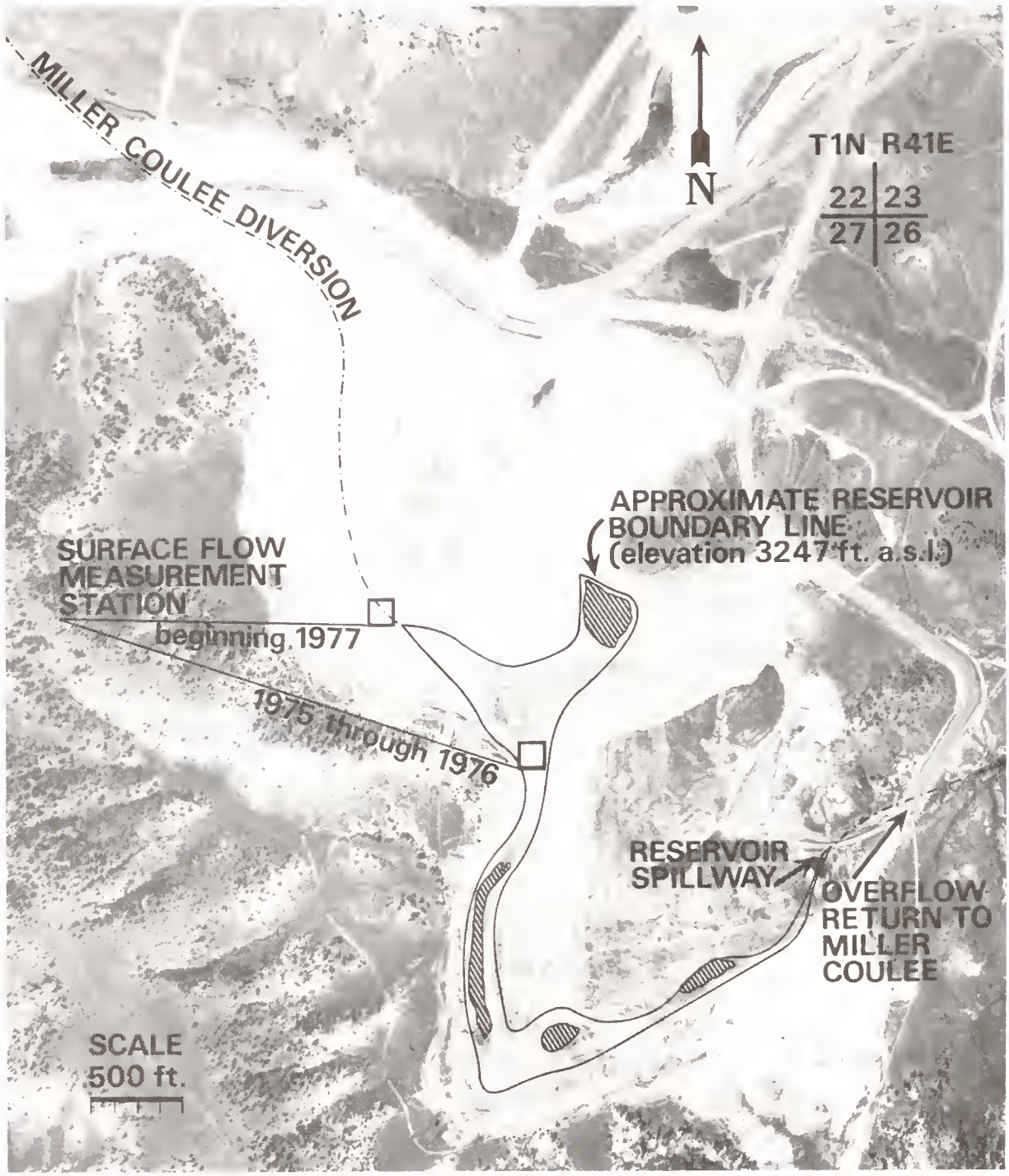

Figure 8. Aerial photo of reservoir area on June 30, 1976. Hash-marked zones denote the extent of the reservoir surface water area (see Figure 1 for location).

volume of pit water encountered in the mining operation which was pumped via a piepline to a siltation pond about 0.8 km (.5 mi) upslope from the reservoir. Much of this pumped pond water drained into the reservoir. In 1977, the intended 1070 hectare Miller watershed drainage area into the reservoir is expected to be restored.

This report on the reservoir hydrology covered a period when complications did not permit implementation of the intended reclamation plan. However drainage from the 80 hectare watershed and pumped water caused substantial reservoir stage fluctuations which permitted some analysis on the behavior patterns of this reservoir in spoils. It is hoped that this research will provide a better understanding of mined land hydrology and water conservation. Figures 9 - 15 pictorially illustrate the study area.

Reservoir Monitoring Program

Hydrologic features of importance to the reservoir evaluation include precipitation, surface water inflow and outflow, reservoir stage, evaporation and seepage. Each of these features, with the exception of seepage, is currently being monitored by MAES and Peabody Coal Company. The Montana Bureau of Mines and Geology recently installed a number of observation wells in the reservoir area for the purpose of relating reservoir stage to groundwater levels near the reservoir. The combination of these data should result in a better understanding of reservoir behavior in spoil materials. The following paragraphs disucss the monitoring equipment and techniques now utilized by MAES at the reservoir site.

Precipitation data were recorded by Peabody Big Sky Mine staff with a Standard U.S. Weather Storage Rain Gauge and a Recording Tipping Bucket

Figure 9. A portion of the reservoir constructed in spoils, November 16, 1976. Peabody Big Sky Mine, Colstrip, Montana.

Figure 10. A portion of the Miller Coulee diversion drainage way (inlet channel to reservoir), flume, Manning water sampler and evaporation pan. Peabody Big Sky Mine, Colstrip, Montana (October, 1976).

Figure 11. Reservoir impoundment showing staff gauge to the right of photo, Peabody Big Sky Mine, Colstrip, Montana (staff gauge installed by Montana Bureau of Mines and Geology) (October, 1976).

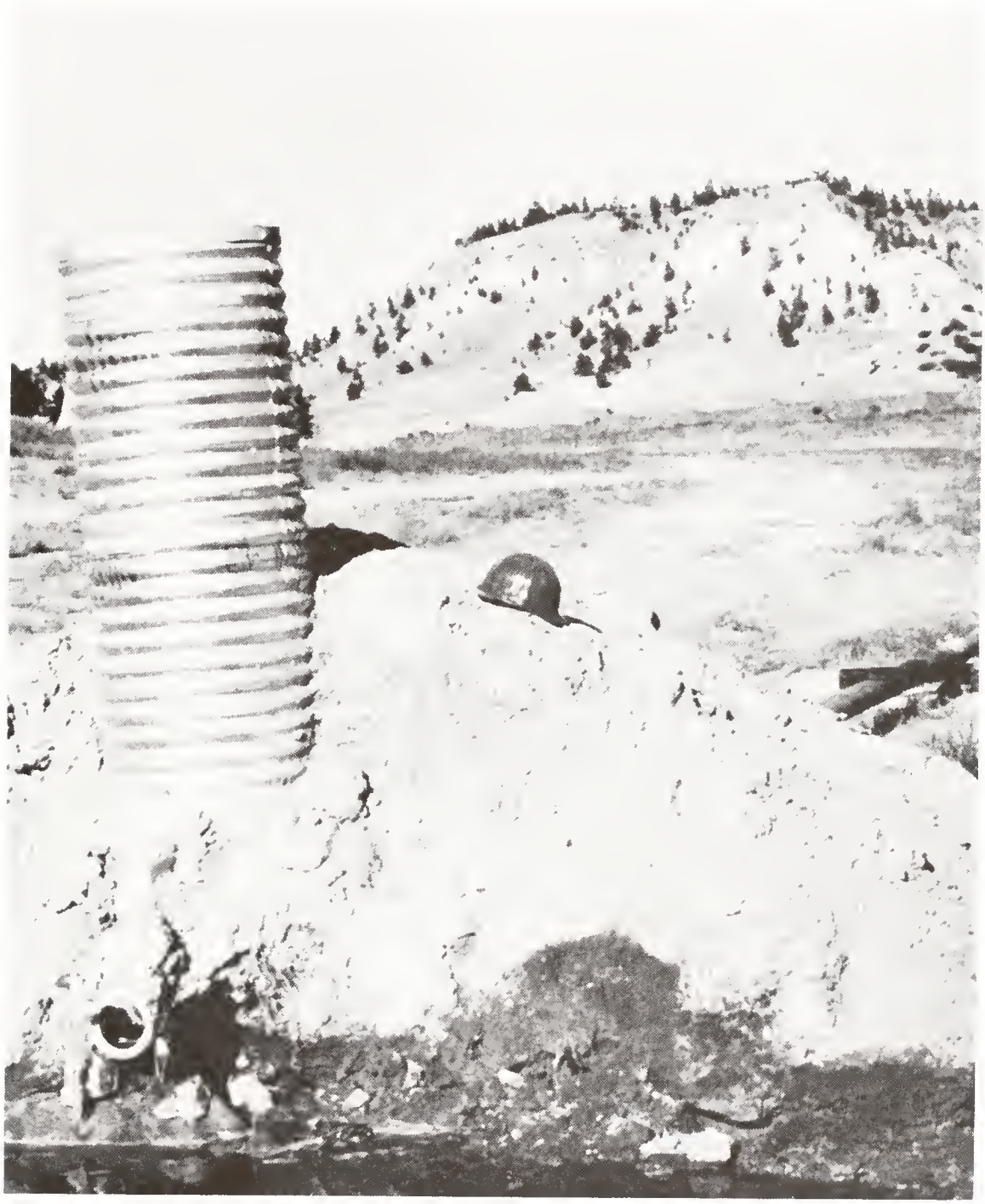

Figure 12. Stilling well type flowmeter (Stevens Type F recorder enclosed inside) and outlet pipe for all pumped flow events. This site is located upslope from a siltation pond and the reservoir, Peabody Big Sky Mine, Colstrip, Montana. Installed and monitored by the Montana Bureau of Mines and Geology (October, 1976).

Figure 13. Siltation pond for all pumped flow events into the reservoir, Peabody Big Sky Mine, Colstrip, Montana (October, 1976).

Figure 14. Pumped flow event through the 1.37 m H-flume, November 16, 1976, Peabody Big Sky Mine, Colstrip, Montana (October, 1976).

Figure 15. Inlet channel erosion between the siltation pond and H-flume. Peabody Big Sky Mine, Colstrip, Montana (October, 1976).

Rain Gauge (Figure 1). Data from the recording Tipping Bucket Rain Gauge, located 23 m north of the mine office, were utilized until March 1, 1976. In March, 1976, the Standard U.S. weather storage rain gauge was installed 100 meters east of the mine shop. Comparison between the two rain gauges showed a difference factor of 2.5 times with the U.S. weather gauge giving higher readings. The proximity of the tipping bucket electric rain gauges to buildings may have caused problems. A review on the operations of these two rain gauges indicated the tipping bucket gauge probably contained the substantial error in precipitation measurement. Based on these preliminary findings, all data collected by the tipping bucket gauge before March 1, 1976, were multiplied by the 2.5 factor to give the approximate corrected reading comparable to data used after March 1, 1976.

Surface inflow events from the 80 hectare mined land watershed were monitored with a 1.37 meter deep H-flume (Holtan, 1968) built within the inlet channel of the reservoir (Figure 10). The head of water flowing through the precalibrated flume is measured by a Leopold and Stevens type F water level recorder. The recorder is fitted with a paper strip chart which is monitored at 16 day intervals.

To measure surface water evaporation from the reservoir, a stainless steel metal pan, 120.65 cm in diameter and 25.4 cm deep, was installed 3 m southeast of the flume on May 3, 1976 (Figure 10). This standard Weather Bureau Class A pan is the most widely used evaporation pan in the United States. The pan was filled with water to within 2.5 inches of the top, thus allowing for raindrop splash and/or large rain storms. A stilling well, equipped with a Leopold and Stevens Type F 16 day water level recorder, maintained a continuous record of water level variation in the pan.

The reservoir stage was monitored on a monthly basis and more frequently during certain months. Two techniques were utilized to record the water level in the reservoir. Initially, the inlet channel from the reservoir floor to flume was surveyed with twenty-one metal stakes installed at 30.48 cm elevation intervals. The reservoir stage was measured to the nearest millimeter above the top of the last submerged stake. On April 10, 1976, the stakes were correlated with a recently installed 304.8 cm staff gauge rod placed between stakes two and three (Figure 11). The staff gauge was installed by the Montana Bureau of Mines and Geology. The two methods complemented each other depending on seasonal changes. The stakes were more useful when ice and snow covered the reservoir. It should be noted that these stage measurements did not begin at the base of the dry reservoir. Rather a considerable amount of water already existed in the reservoir at the initiation of this research.

In April 1977 installation was completed on a stilling well, equipped with a Leopold and Stevens Type F 16 day water level recorder, which shall maintain a continuous record of stage variation in the reservoir.

According to reclamation contours, surface outflow will not occur until the reservoir surpasses a maximum depth of 15.24 meters. Therefore, this hydrologic component will equal zero during the early phases of this study.

Results and Discussion

Annual hydrologic data are summarized in Figures 16 and 17. Numerical values for these data are listed in Tables 3, 4, and 5.

Monthly precipitation levels correlate very well with the frequency of natural flume discharge events (Figure 16). Most surface runoff occurred

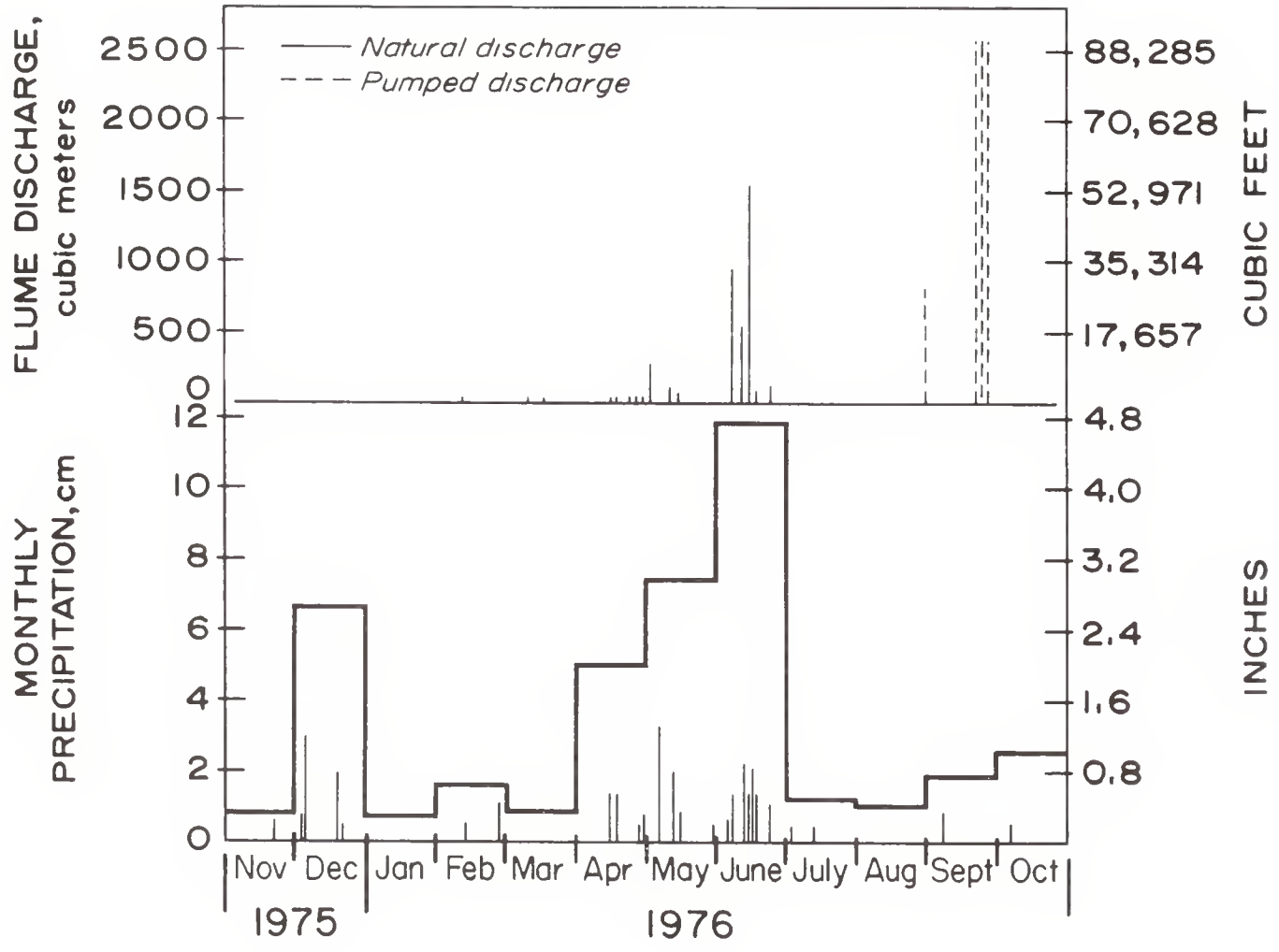

Figure 16. Flume discharge events and monthly precipitation. Daily precipitation is shown for storms greater than 0.5 cm.
Peabody Big Sky Mine, Colstrip, Montana

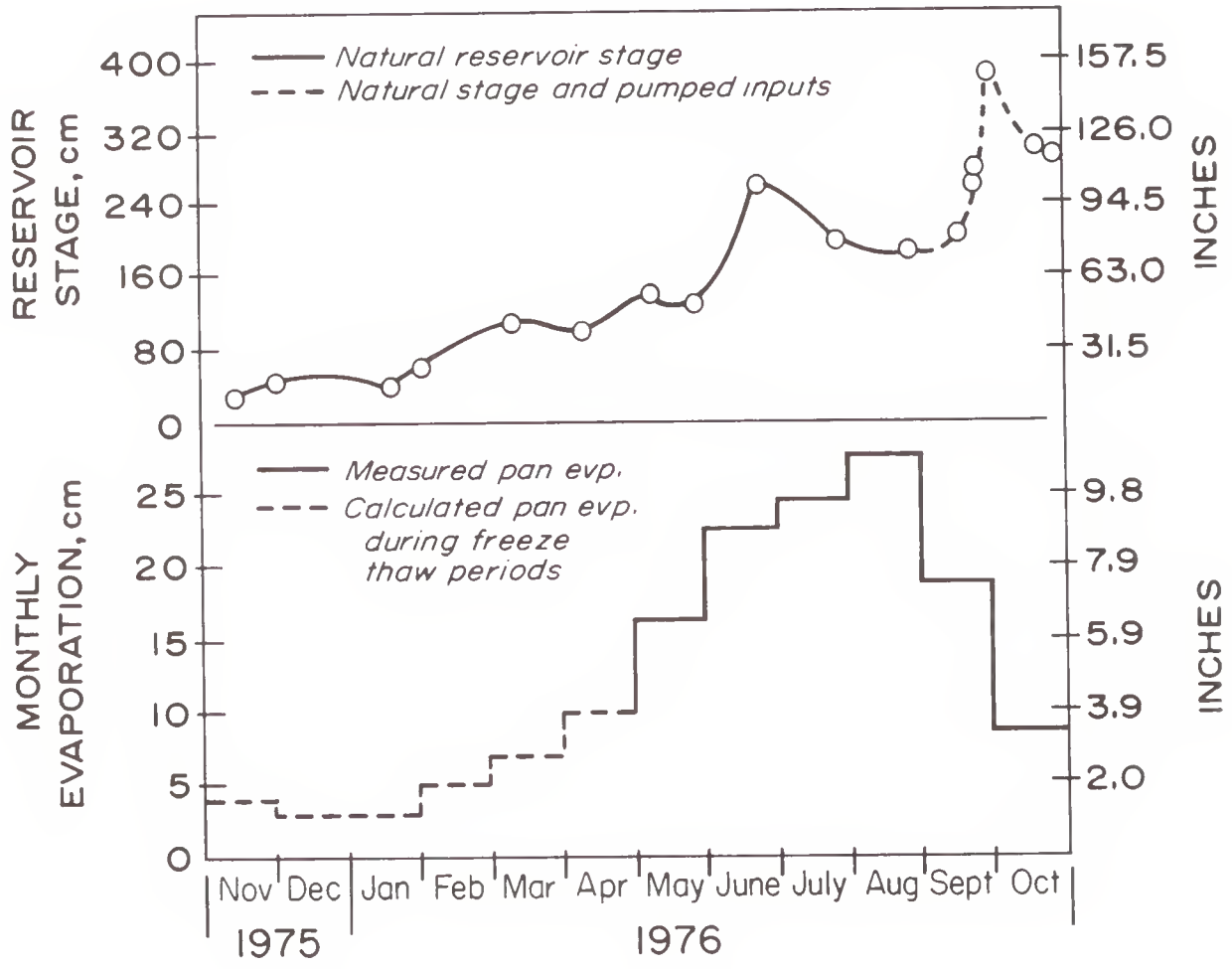

Figure 17. Reservoir stage and monthly pan evaporation. Peabody Big Sky Mine, Colstrip, Montana

Table 3. Daily precipitation events (cm), for hydrologic year 1975-1976, Peabody Big Sky Mine, Colstrip, Montana.

Mo/day	Quantity	Mo/day	Quantity	Mo/day	Quantity	Mo/day	Quantity
11/17	0.05	3/02	0.22	5/15	0.91	7/22	.15
11/21	0.69	3/10	0.18	5/21	0.31	8/03	0.36
11/22	0.05	3/12	0.18	5/26	0.18	8/06	0.05
12/01	0.05	3/15	0.03	5/29	0.56	8/14	0.20
12/02	0.82	3/20	0.15	6/02	0.15	8/18	0.25
12/03	2.98	3/25	0.10	6/05	0.66	8/24	0.13
12/08	0.12	4/02	0.15	6/07	1.40	8/25	0.08
12/19	2.03	4/03	0.10	6/09	0.41	9/07	0.84
12/20	.51	4/14	1.42	6/12	2.23	9/15	0.33
12/27	.12	4/17	1.35	6/14	1.40	9/18	0.25
1/05	0.05	4/18	0.15	6/15	2.16	9/20	0.03
1/09	0.05	4/19	0.03	6/17	1.40	9/27	0.38
1/12	0.45	4/21	0.08	6/21	.25	10/06	0.58
1/16	0.12	4/25	0.25	6/23	1.14	10/12	0.23
1/28	0.05	4/26	0.56	6/24	.25	10/14	0.10
2/06	0.05	4/29	0.89	6/25	.46	10/17	0.38
2/10	0.05	5/05	3.35	7/02	.51	10/18	0.08
2/13	0.57	5/06	0.05	7/12	.51	10/23	0.46
2/16	0.05	5/12	2.06	7/21	.10	10/25	0.43
2/27	0.94						

Table 4. Hydrologic components for the reservoir, Peabody Big Sky Mine, Colstrip, Montana.

1975-76 MONTH	PRECIPITATION Quantity (cm)	PRECIPITATION Events	PAN EVP., (cm)	FLUME DISCHARGE Events	FLUME DISCHARGE Quantity ($meters^3$)	FLUME DISCHARGE Duration (hours)	FLUME DISCHARGE Peak Flow (cm)
NOVEMBER	0.79	3	4.0*	0			
DECEMBER	6.63	7	3.0*	0			
JANUARY	0.74	5	3.0*	0			
FEBRUARY	1.65	5	5.0*	1	Trace	-	2.16
MARCH	0.86	6	7.0*	2	11.07 1.27	35 4	2.04 1.22
APRIL	4.98	10	10.0*	5	0.62 Trace Trace Trace 0.62	6 - - - 6	0.91 0.30 0.30 0.61 1.22
MAY	7.42	7	16.2	3	286.29 84.78 64.88	68 54 21	21.34 9.44 14.02
JUNE	11.91	12	22.6	6	4.08 942.06 557.00 1538.79 103.56 125.59	20 68 64 26 13 72	1.22 100.00 41.76 39.01 9.45 2.13
JULY	1.27	4	24.6	0			
AUGUST	1.07	6	27.6	0			
SEPTEMBER	1.83	5	18.7	2	813.50+ 7884.24+	33 186	14.33 16.15
OCTOBER	2.26	7	9.6	0			
TOTAL	41.41	77	151.3	19	12418.31		

*Calculated winter months +Pumped flows

Table 5. Reservoir stage levels in meters and feet. Peabody Big Sky Mine, Colstrip, Montana (1975, 1976).

Month/Day	Meters	Feet	Month/Day	Meters	Feet
11-14	0.31	1.00	6-23	2.61	8.55
12-2	0.48	1.57	7-29	2.01	6.58
1-20	0.44	1.43	8-26	1.90	6.23
2-3	0.64	2.11	9-18	2.04	6.70
3-10	1.12	3.66	9-24	2.62	8.59
4-10	1.04	3.40	9-25	2.80	9.18
5-9	1.39	4.56	9-30	3.84	12.60
5-27	1.31	4.30	10-22	3.00	9.85
			10-29	2.93	9.60

during April through June when the intensity, level, and frequency of rainstorms were highest. Flume discharge or reservoir surface inflow from natural events totaled approximately 3700 cubic meters (Table 4). The reservoir stage increased 1.57 meters during the period of high precipitation and surface inflow.

As shown in Figure 17 and Table 5, the reservoir stage increased from January through June. The initial increase in January, February and March during a time of relatively little precipitation may be attributed to snowfall accumulation in the reservoir. Much snow was received in December of 1975. The sloping mined land to the northeast of the reservoir has a sparse vegetation cover with no trees or natural wind breaks (Figure 9). As stated by Linsley, et al. (1975), "A small reservoir can trap considerable quantities of blowing snow". This phenomena may have been the contributing factor in the reservoir showing its 60 cm stage increase during January, February and March.

The reservoir stage dropped 70 cm in July and August when the rate of evapotranspiration was highest and precipitation was very low. Declining reservoir stages probably would have continued through September and into October. However, the exact stage at the end of the hydrologic year resulting from natural overland flows is unknown because of the two pumping events that occurred in September.

In Figures 16 and 17, pumped flume discharge events and the resultant reservoir stage increases are indicated with dashed lines. The source of this pumped water was ground water from the pit where mining was active in upper Miller Coulee. This water was pumped through a stilling well type flowmeter (Figure 12) equipped with a Stevens Type F recorder that measures flow rates and discharged into a siltation pond (Figure 13). The overflow from the siltation pond flows down the channel, through the flume, and into the reservoir. (One of these flows is shown in Figure 14).

These low-intensity, long-duration, pumped-flow events presented a siltation problem. Sediment eroded from the channel between the siltation pond and flume (Figure 15) was deposited and accumulated on the flume floor. Daily to weekly servicing was necessary to adequately clear the flume of sediment. There was little continuous sediment problem with natural flows.

Summary

Results of the first year's monitoring at the reservoir site pointed out the need for several refinements and additions to the initial program. These include alterations of the inflow-flume design to reduce sediment accumulation in the flume, investigation of methods to correlate pan evaporation during all seasons of the year, completion of a detailed

bathymetric survey of the reservoir, development of flume discharge - reservoir stage rating curves, and continuous monitoring of ground-water levels adjacent to the reservoir. Each of these activities should supplement existing data and lead to a better understanding of the water holding and seepage characteristics of the spoil materials. It is anticipated that these refinements and additions to the initital program will be completed in the coming year.

It is anticipated that the planned diversion of Miller Coulee will also take place within the next year. The completion of this diversion together with evaluation of the additional data should result in a more quantitative analysis of the water balance at the reservoir as well as provide some guidance on the feasibility of sustaining a reservoir in spoil materials.

WATER QUALITY

WATER QUALITY

The principal objectives of the water quality monitoring program at the Big Sky Mine are: (1) to evaluate baseline chemical characteristics of waters not now affected by mining activites, (2) to observe any changes in ground and surface water quality resulting from mining of the Rosebud and McKay coal, and (3) to provide some means of predicting the time and location of impacts on water quality resulting from the disruption of shallow aquifers and discharge or runoff from mine areas. Adverse effects could include: (1) leaching of solute through spoils and into the aquifer system, (2) increased erosion and downstream deposition of unconsolidated spoils materials, and (3) accelerated release of nutrients associated with revegetation of the spoils areas when fertilizers are used.

The following sections discuss techniques used by the Montana Agricultural Experiment Station to collect the necessary information and also provide preliminary descriptions of the chemical characteristics of ground and surface water at the Big Sky Mine.

Monitoring Program

A network of water quality monitoring stations was installed at the Peabody Big Sky Mine (Figure 1). The ground-water quality monitoring system consisted of wells to observe hydrochemical characteristics in alluvial deposits, shallow sands and sandstone of the Fort Union formation, and the Rosebud coal. These are the geologic materials most directly affected by mining. Automatic surface water sampling instruments have been installed in Coalbank Coulee, in Miller Coulee within a drainage channel downslope from a reclaimed spoils area, and at the entrance to the reservoir

also in the Miller Coulee watershed. In addition, periodic samples are collected from the reservoir.

Ground-water samples have been collected and analyzed for the past several years in conjunction with the water level monitoring program discussed in the previous chapter. Selected wells (Figure 1) were dip sampled (lowering of a bottle into the well to collect the sample) or pumped to obtain the water for analysis. Surface water samples from Coalbank Coulee, the inflow flume, and east of the reclaimed spoils area were collected with a Manning automatic water sampler. The reservoir was dip sampled. Sample bottles were treated with preservatives and then kept refrigerated. Table 6 describes the current preservation methodology as recommended by the Environmental Protection Agency (1974).

The H_2SO_4 treatment and the refrigeration act as bacterial inhibitors. The HNO_3 treatment prevents metal precipitation. When new sample containers were unavailable, previously used bottles underwent a cleansing process before each use which included scrubbing with soap, rinsing several times with tap water, rinsing with dilute HCL solution and finally rinsing several times with distilled water. In addition, containers are now rinsed three times with water to be sampled before obtaining the final sample.

The filled containers were transported to the lab at Montana State University in ice chests filled with crushed ice to maintain the proper temperature. Unavoidable delays due to long travel times sometimes prohibit analyses of the samples within the recommended time limits of the Environmental Protection Agency (1974). The most noticeable effects of this delay would be reflected in the determinations for alkalinity, bicarbonate, carbonate, pH (when not measured in the field), nitrate and phosphate-P. Procedures

Table 6. Water sample preservation treatment and corresponding analysis performed. All samples were refrigerated after collection.

Preservation Treatment	Analyses Performed
None	pH, electrical conductance, SO_4, CO_3, HCO_3, PO_4-P, Cl, B, settleable matter*
H_2SO_4 to pH < 2	NO_3
HNO_3 to pH < 2	Se, Ca, Mg, Na, K, Mn, Cu, Zn, Pb, Cd, Fe (dissolved metals)

*Settleable matter only for surface water

for measuring these parameters in the field are presently being evaluated. Specific procedures presently used in the laboratory for analysis of the water samples are summarized in Table 7.

To provide some objective basis for evaluating the quality of ground and surface water in the mine area, these characteristics were compared with limits established by the U.S. Public Health Service for drinking water standards (Table 8). Table 9 presents the recommended surface water criteria for public water supplies.

Table 7. Summary of laboratory procedures for water analyses used by the Reclamation Research laboratory at Montana State University, Bozeman.

Element	Procedure*+
Pb, Cd, Cu, Fe, Zn, Mg, Mn, Ca, Na, K	Atomic Absorption Spectorscopy
Se	Gaseous Hydride Method
Settleable Matter	Imhoff Cone
pH	Electrode
Conductivity	Conductance Bridge-Meter
HCO_3, CO_3	Titration
Sulfate	Turbidimetric
PO_4-P	Persulfate digestion--colormetric
Boron	Curcumin Method
Nitrate-N	Cd reduction

*All procedures were from "Methods for Chemical Analysis of Water Wastes" EPA (1974).

+All metal analyses are for dissolved metals. EPA specifications state water samples for dissolved metal analyses should be filtered as (.45 micron) soon as possible to remove sediment material. This operation was performed in the lab at Montana State University which was generally several days after the sample had been collected at the field sites. Currently, filtering is done in the field at the time of sample collection.

Table 8. Drinking water standards of the U.S. Public Health Service*.

Substance	Recommended Limits of Concentration (mg/l)	Mandatory Limits of Concentration (mg/l)
Arsenic (As)	0.01	0.05
Barium (Ba)	-	1.0
Cadmium (Cd)	-	0.01
Chloride (Cl)	250.0	-
Chromium (Cr^{+6})	-	0.05
Copper	1.0	-
Cyanide (Cn)	0.01	0.2
Fluoride (F)	0.6 - 1.7	-
Iron (Fe)	0.3	-
Lead (Pb)	-	0.05
Manganese (Mn)	0.05	-
Nitrate (NO_3)	45.0	-
Phenols	0.001	-
Selenium (Se)	-	0.01
Silver (Ag)	-	0.05
Sulfate (SO_4)	250.0	-
Total dissolved solids	500.0	-
Zinc (Zn)	5.0	-

*United States Public Health Service Standards, 1962. Public Health Service Publication 956.

Table 9. Recommended surface water criteria for public water supplies.*

Constituent or Characteristic	Permissible Criteria mg/l	Desirable Criteria mg/l
Ammonia	0.5 (as N)	< 0.01
Arsenic	0.05	Absent
Barium	1.0	Absent
Boron	1.0	Absent
Cadmium	0.01	Absent
Chloride	250.0	<25
Chromium (Cr^{+6})	0.05	Absent
Copper	1.0	Virtually absent
Iron (filterable)	0.3	Virtually absent
Lead	0.05	Absent
Nitrates plus nitrites	10 (as N)	Virtually absent
pH (range)	6.0 - 8.5	-
Selenium	0.01	Absent
Silver	0.05	Absent
Sulfate	250.0	<50
Total dissolved solids (filterable residue)	500.0	< 200
Zinc	5.0	Virtually absent

*Report of the Committee on Water Quality Criteria, F.W.P.C.A., U.S. Department of the Interior

Ground-Water Quality

Chemical constituents in ground water are derived principally from the soluble materials in the soil and rock through which the water has moved. It might, therefore, be expected that the quality of ground water which passes through the disrupted portion of an aquifer may be modified by contact with the spoil material. The quality of ground water may also be affected by recharge from a surface water impoundment or drainage way.

The ground-water monitoring program at the Big Sky Mine has been designed to monitor: (1) baseline water quality in the unmined Rosebud coal in upper Coalbank Coulee (wells 63, 65 and 68); (2) changes in quality of the water in the alluvium downstream from mining activities in lower Coalbank Coulee (wells 13 and 27); and (3) water quality characteristics immediately northwest of present mining operations in Miller Coulee (wells CW and UW). Well locations are shown in Figure 1.

Results of ground-water quality analyses are presented in Table 10. and discussed in the following paragraphs. When relatively complete analyses were made of the samples, the results were reviewed with regard to charge mass balance. The purpose of this check was to identify, if possible, any contaminated samples or procedural errors in analyses. Theoretically, the sum of anions, expressed in milliequivalents per liter, must equal the sum of cations in milliequivalents per liter, in any water sample. In practice, the sums are seldom equal because of unavoidable variations in the analyses (Amer. Pub. Health Assoc., 1965). This inequality increases as the ionic concentration increases. A factor which may affect the balance is the presence in the sample of undetermined species.

Table [illegible] Chemical analyses of ground water from observation wells at the Peabody Coal Company Big Kyrock Mine, Muhlenberg County, Kentucky

Well Number	Date Sampled	pH (Laboratory)	Specific Conductance (micromhos/cm)	Calcium (Ca) mg/l	Magnesium (Mg) mg/l	Sodium (Na) mg/l	Iron (Fe) µg/l	Manganese (Mn) µg/l	Zinc (Zn) µg/l	Lead (Pb) µg/l	Cadmium (Cd) µg/l	Selenium (Se) µg/l	Boron (B) µg/l	Bicarbonate (HCO3) mg/l	Sulfate (SO4) mg/l	Chloride (Cl) mg/l	Nitrate-N (NO3-N) mg/l	Phosphate (PO4) mg/l	Total Dissolved Solids mg/l	Acidity (CaCO3) mg/l
1	03/21/75	-	-	102	29	90	-	370	-	5	-	-	1.6	-	-	-	-	-	96	-
1	04/21/75	-	-	92	130	1.4	-	204	4	5	5	-	3.6	-	-	-	-	-	10	-
1	05/21/75	-	-	61	118	67	-	108	8	5	5	-	1.7	-	-	-	-	-	01	-
1	08/10/75	-	1400	200	261	75	-	295	9.5	5	5	-	1.5	-	-	-	-	-	01	-
	09/18/75	-	3200	62	37	21	-	2.1	89	5	5	-	3.8	-	-	-	-	-	-	-
	10/09/75	-	2700	121	90	56	-	160	3	63	21	-	4.5	-	-	-	-	-	01	-
1	11/14/75	-	-	96	45	42	-	240	14	25	20	-	4.5	-	-	-	-	-	66	-
1	01/16/76	-	-	132	-	11	772	180	0	12	0	0	0	-	-	1.93	0	2	90	-
1	03/15/76	-	-	80	105	62	445	64	5	10	20	-	1.1	-	-	-	-	-	01	-
1	05/10/76	-	-	246	320	122	2600	35	92	26	140	4	-	-	-	1.96	-	-	01	-
1	06/27/76	8.1	2400	104	110	30	860	79	15	10	10	4	-	-	-	-	-	-	01	-
1	08/22/76	8.1	3200	244	310	128	3040	195	20	29	20	13	-	741	-	-	20.8	3	02	-
1	10/06/76	8.1	2300	264	45	100	1410	145	25	15	80	10	89	456	-	-	19.0	14	01	-
	01/14/75	-	-	4	32	16	-	56	1	5	5	-	-	-	-	-	-	-	-	86
	04/21/75	-	-	62	219	8	-	102	1	5	-	1.4	-	-	-	-	-	-	-	86
	05/15/75	-	-	61	75	22	-	74	10	5	5	2	-	-	-	-	-	-	-	-
	08/18/75	-	580	205	114	1	-	176	19	10	-	-	-	-	-	-	-	-	-	-
	09/15/75	-	1480	108	123	108	-	82	37	0	238	-	0	-	-	-	-	-	03	-
	10/09/75	-	2500	112	113	114	-	198	37	8	205	-	-	-	-	-	-	-	02	-
	11/14/75	-	-	86	61	8	-	126	29	15	280	-	5	-	-	-	-	-	02	-
h	01/16/76	-	-	124	95	7	2460	209	20	247	31	0	2	-	-	1.03	-	-	01	-
h	03/15/76	-	-	174	44	141	635	102	5	57	25	11	-	-	-	-	-	-	01	82
h	05/10/76	-	-	262	227	102	425	60	126	47	70	7	11	-	-	1.62	-	-	06	78
h	06/27/76	8.6	1600	270	146	58	9000	550	71	97	141	14	-	240	-	-	4.0	-	01	184
h	08/22/76	7.8	3200	272	42	93	8610	525	20	65	20	18	-	208	-	-	3.6	-	01	184
h	10/06/76	8.1	2600	295	60	118	9760	563	25	140	1	5	-	510	-	-	3.0	-	11	161
13	01/16/76	-	-	65	46	6	65	14	1	95	0	0	-	-	-	-	-	-	11	-
13	03/14/76	-	-	71	93	4	80	0	0	42	0	2	06	-	-	-	-	-	01	-
13	05/10/76	-	-	188	142	134	57	10	89	29	664	6	-	-	-	1.61	-	-	01	161
13	06/27/76	8.1	1650	80	98	29	50	13	16	10	10	4	-	-	-	-	1.24	0	-	-
13	08/22/76	8.2	3600	239	346	142	1600	24	20	18	13	16	-	493	1	-	4.7	0	-	132
13	10/30/76	8.2	2800	114	160	118	172	65	24	20	28	10	12	406	-	-	3.0	-	01	146
13	11/14/76	8.1	2500	131	155	104	670	260	20	20	10	5	98	305	-	-	3.0	-	11	146
[illegible]	01/10/76	-	-	21	134	6	141	12	10	10	0	-	-	-	15	0	-	-	01	11
[illegible]	03/14/76	-	-	95	109	36	148	41	6	13	14	6	-	-	114	-	-	-	11	71
[illegible]	05/10/76	-	-	114	140	17	94	30	80	48	41	6	-	-	166	-	-	-	01	63
[illegible]	06/27/76	8.2	1300	72	96	17	100	20	19	20	10	4	-	220	0	1.53	-	-	02	59
[illegible]	08/22/76	7.9	1750	108	190	49	172	75	20	323	16	9	-	424	-	-	1.7	-	-	141
[illegible]	10/06/76	8.1	1600	100	125	40	2300	116	24	33	11	-	20	134	-	-	2.1	-	4	122
[illegible]	11/14/76	8.3	1900	90	110	88	140	110	34	19	10	-	41	11	-	-	2.0	-	01	122
[illegible]	01/10/76	-	-	140	148	160	693	240	5	172	11	9	11	-	-	1.12	-	-	01	96
[illegible]	03/14/76	-	-	107	140	114	486	300	76	91	50	4	-	-	-	1.1	-	-	11	71
[illegible]	05/10/76	8.0	2300	14	165	30	200	148	24	10	10	4	-	674	-	-	1.1	-	15	71
[illegible]	06/27/76	7.9	2800	240	317	15	39	280	20	51	10	1	-	988	0	1.8	4.1	-	11	73
[illegible]	10/30/76	8.1	2400	130	140	98	220	305	17	12	40	-	32	488	0	1.7	4.1	-	17	45
[illegible]	[illegible]	-	-	166	31	1	542	162	1	54	10	0	-	-	-	-	-	-	-	14
[illegible]	03/14/76	-	-	44	116	56	310	76	1	20	20	4	1	-	-	1.86	-	-	01	-
[illegible]	[illegible]	-	-	196	218	100	118	142	13	22	10	4	-	-	-	1.94	-	-	04	67
[illegible]	06/27/76	8.1	2700	115	150	60	200	100	30	10	10	-	-	84	-	-	-	-	02	44
[illegible]	08/22/76	7.7	4100	220	360	138	1200	196	30	18	20	4	-	1061	-	-	1.1	-	01	122
[illegible]	10/06/76	8.1	2500	29	90	76	380	140	15	12	10	-	19	380	0	-	0.0	-	-	49
[illegible]	11/15/76	8.0	1300	93	110	7	434	170	32	10	10	-	43	401	0	-	0.0	0	-	73
[illegible]	[illegible]	-	-	29	24	20	80	5	5	125	15	1	-	-	-	-	-	-	66	-
[illegible]	[illegible]	-	-	4	30	14	96	41	64	60	60	-	-	-	-	-	-	-	41	-
[illegible]	[illegible]	7.4	440	20	14	9	20	28	14	10	10	-	-	183	-	-	-	-	36	4
[illegible]	[illegible]	7.8	470	68	62	26	10	18	0	5	10	-	-	18	-	-	1.1	-	17	5
[illegible]	[illegible]	7.8	800	5	43	19	197	141	0	43	10	-	-	98	-	-	-	-	-	4
[illegible]	[illegible]	7.4	1100	1	31	16	441	11	0	44	10	-	52	281	-	-	-	-	-	4
[illegible]	[illegible]	-	-	1	13	11	-	86	4	5	-	1.2	-	-	-	-	-	-	16	-
[illegible]	06/[illegible]	-	-	16	35	11	-	93	1	5	-	1.4	-	-	-	-	-	-	36	01
[illegible]	08/22/76	-	-	8	5	1.2	-	12	1	5	-	1.1	-	-	-	-	-	-	11	11
[illegible]	[illegible]	-	-	9	30	5.5	-	22	1	5	-	1.2	-	-	-	-	-	-	18	11
[illegible]	[illegible]	-	340	31	14	5	-	145	19	5	-	1.4	-	-	-	-	-	-	03	11
[illegible]	[illegible]	-	140	10	14	1.9	-	226	10	5	-	1.2	-	-	-	-	-	-	03	11
[illegible]	[illegible]	-	280	19	8	1	-	340	28	0	15	1.1	-	-	-	-	-	-	01	11
[illegible]	[illegible]	-	-	1	14	1	-	30	31	11	11	8	-	-	-	-	-	-	11	11
[illegible]	[illegible]	-	-	19	8.4	3	14400	19	1	1	0	3	-	-	-	1.1	-	-	11	14
[illegible]	[illegible]	-	400	40	19	5	10800	1750	49	40	10	5	03	-	-	-	-	-	14	14
[illegible]	[illegible]	-	-	5	10	14	-	22	8	5	1	1.4	-	-	-	-	-	-	39	58
[illegible]	05/[illegible]	-	-	13	60	16	-	2	1	5	-	1.4	-	-	-	-	-	-	37	45
[illegible]	08/22/76	-	-	11	50	16	-	2	1	5	-	1.4	-	-	-	-	-	-	01	45
[illegible]	[illegible]	-	-	10	39	13	-	4	1	5	-	1.4	-	-	-	-	-	-	13	45
[illegible]	[illegible]	-	100	12	66	20	-	10	1	5	1	1.4	11	-	-	-	-	-	01	45
[illegible]	08/[illegible]	-	700	24	42	14	-	57	13	5	1	1.4	3.4	-	-	-	-	-	11	45
[illegible]	10/09/75	-	470	20	26	12	-	10	30	0	-	1.2	2	-	-	-	-	-	11	45
[illegible]	11/14/75	-	-	206	41	1	-	960	32	86	210	-	-	-	-	-	-	-	11	45
[illegible]	01/06/76	-	-	30	33	1.0	11700	162	4	73	0	0	-	-	-	1.44	-	-	11	13
[illegible]	03/15/76	-	-	14	35	1	12700	13	5	18	20	-	1.1	-	-	1.89	-	-	11	39
[illegible]	[illegible]	-	-	69	45	11	6200	406	11	118	20	-	-	-	-	1.56	-	-	01	58
[illegible]	06/27/76	7.8	410	56	30	11	15000	120	18	10	10	-	-	111	0	1.61	-	-	-	47
[illegible]	08/22/76	7.6	650	84	68	14	17400	975	20	223	10	1.1	-	562	1	-	0.4	-	03	47
[illegible]	10/30/76	8.6	410	47	25	9	22000	240	29	54	41	5	-	136	-	111	3	-	-	31

Note: [illegible] multiscreened zones - wells #1, 5, 13, and 14 - sands in the Tradewater Formation; wells #11 and [illegible] - [illegible] Creek Coal; #61, 65, 68 - Paradise Coal

Major features of the ground-water quality are summarized in Table 11. Specific conductance, an indication of dissolved solids concentration, ranged from 280 to 3400 µmhos/cm. Lowest values were consistently found in samples from the CW and UW wells immediately northwest of the present mining activities. Van Voast and Hedges (1976) report that for water from springs and wells in the Colstrip area, the dissolved solids concentrations in mg/l equals about 0.8 times the water specific conductance in µmhos/cm. This suggests that ambient concentrations of dissolved solids in ground water at the Big Sky mine area generally exceed recommended limits for drinking waters (Table 8).

The dominant cations in each of the monitored areas were calcium and/or magnesium. An interesting trend was observed in the fall of 1975 for wells 6 and CW, both located in Miller Coulee watershed. During this period, calcium replaced magnesium as the major cation in both wells. The magnitude of change was relatively small in both cases, but the trend has continued to date. It is our feeling that this change, although interesting, cannot at this time be related to mining activities. The dominant anions were sulfate in all but the CW and UW wells, in which the major anion was bicarbonate.

The sodium adsorption ratio (SAR) represents a relationship between sodium, calcium and magnesium. The SAR concept is important regarding the suitability of waters for agricultural irrigation. The sodium content of a soil system can increase when irrigation water is applied with SAR >15. This is an undesirable process since the result could be a development of a soil with sodic characteristics. Such soils have poor physical properties, very low infiltration rates and can create difficulties

Table 11. Summary and comparison of water quality characteristics of ground and surface water at the Peabody Coal Company Big Sky Mine near Colstrip, Montana.

	GROUND WATER				SURFACE WATER			
Station Numbers / Location / Monitored Zone / Criteria for Comparison	Wells 63, 65, 68 Upper Coalbank Coulee Unmined Rosebud Coal (4)	Wells 13, 27 Lower Coalbank Coulee Alluvium	Wells CW, UW NW of present mining Near surface Fort Union material	Wells 1, 6 E of reclaimed spoils Near surface Fort Union material	A.W.S.[1] C Coalbank Coulee	A.W.S. B Miller Coulee Spoils runoff	A.W.S A Reservoir Inflow Flume Watershed Drainage (3)	Reservoir Miller Coulee Watershed Drainage (3)
Specific Conductance (μmhos/cm)	490 - 3300	1200 - 3400	280 - 850	1480 - 3400	360 - 420	440 - 1000	230 - 1900	230 - 2100
Dominant Cation	Ca, Mg	Mg	Ca, Mg	Mg, Ca	Ca	Ca	Ca	Ca
Dominant Anion	SO_4	SO_4	HCO_3	SO_4	SO_4	I.D.	SO_4	SO_4
SAR	.35 - 1.94	.11 - 1.81	.01 - .58	.12 - 2.55	.08 - .31	.07 - .20	.03 - 1.09	.03 - 1.00
Dominant Trace Elements	Fe, Mn	Fe, Mn	Fe, Mn	Fe, Mn	Fe, Mn	Fe, Mn	Fe, Mn	Fe, Mn
Exceed Recommended Limits (Table 5-3)	SO_4 - all Fe, Mn - 63, 65	SO_4 - all Fe, Mn - rarely	Fe - all Mn - all	Fe - all Mn - all SO_4 - all	Fe, Mn	Fe, Mn	Fe, Mn	Fe - rarely Mn - rarely
Increasing Concentrations	Mn - 68 Fe - 68	Mn - 13, 27	Zn - CW	None	I.D.[2]	Mn	SO_4, Na NO_3, Fe	Variable
Decreasing Concentrations	Fe - 63 Zn - 63, 65, 68	None	None	None	I.D.	I.D.	None	None

(1) A.W.S. = Automatic Water Sampler
(2) I.D. = Insufficient Data
(3) Received pumped water beginning September, 1976
(4) May have been partially mixed with overburden water in annular space of the wells

associated with soil-water plant relations. The SAR levels in ground water sampled at the Big Sky mine were low, usually less than 3.0.

The dominant trace elements in ground water sampled at the site were iron and manganese. Concentrations of these substances in the sampled wells generally exceeded recommended limits (Table 8). Exceptions were wells 13 and 27 in the alluvium. In these wells, concentrations of iron and manganese seldom exceeded recommended limits, although manganese is showing a slightly increasing trend in both wells. Manganese also appears to be increasing in well #68 in upper Coalbank Coulee in conjunction with a similar increase in iron. Zinc appears to be increasing in concentrations at the CW well in Miller Coulee but decreasing in wells 65 and 68. Iron and zinc both appear to be decreasing in well 63. The reason for, or significance of, these changes cannot be explained at this time.

The information collected to date does not support a specific relationship between water quality and either aquifer stratigraphic horizons or aerial variation. As of the date of this report, mining activities at the Big Sky Mine do not appear to have resulted in significant adverse effects on the ground-water quality, at least not at the observed stations during the period of this monitoring program.

Surface-Water Quality

The chemical composition of surface water depends on many factors. These include the source, the climate, the soil, the geology and other conditions within the watershed. Surface water characteristics are also subject to seasonal and daily changes due to man-induced stresses and climatic influences. The influence of man's activities in strip-mining

areas is particularly significant due to the constant shifting and resultant loosening of consolidated overburden material, necessary dewatering activities, and alteration of natural drainage channels.

Natural surface water runoff events are relatively infrequent in semiarid climates. Because of this unpredictability, automatic water samplers were installed to collect samples during each runoff event. Units were set to collect a sample at the event initiation and at equal time increments until the event ended or the 24-bottle capacity was filled. The sampler is designed with a high velocity fluid transport system to help prevent settling out of suspended solids, thus, a rather representative sediment sample can be obtained. Three of these units were installed. Sampler A is at the inflow flume of the reservoir to monitor water which will eventually fill the reservoir (Figure 1). Sampler B is also located in Miller Coulee on the downslope, eastern side of a reclaimed spoils area. It was felt this location might result in spoils runoff water quality data. Sampler C was installed near well #13 in Coalbank Coulee to monitor the quality of water during runoff events in that watershed.

A summary of general surface and ground-water chemical characteristics is presented in Table 11. Data collected during the surface water quality monitoring program are presented in Table 12. As previously mentioned, a Manning water sampler was used to collect samples from Stations A, B, and C. Three sample bottles were generally required to obtain a complete chemical analysis due to the need for the different preservation treatments. As a result, analysis for a single date, shown in Table 12 usually represent a combination of samples which may have been obtained several hours or several days apart. This technique could result in chemical relationships which

ible 2. Chemical analyses of surface water samples collected at the Peabody Coal Company Big Sky Mine near Colstrip, Montana.

Date of Collection	pH (Laboratory) (*Field)	Specific Conductance	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Lead (Pb)	Cadmium (Cd)	Boron (B)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate-N (NO_3-N)	Phosphate-P (PO_4-P)	TDS (Calculated)	SAR	Comments**
		umhos/cm	mg/l			µg/l						mg/l									
Reservoir																					
06/13/75	-	-	48	62	14	-	-	< 1	5	< 5	-	-	-	-	-	-	-	.02	-	31	Se=3.2
06/13/75	7.5	600	4	4	1	1.6	-	-	-	-	-	-	204	0	-	20	2.0	.01	-	.08	
07/15/75	-	-	23	24	5	-	-	1	5	< 5	-	-	-	-	-	-	-	.01	-	07	Se=1.9
08/10/75	-	2100	90	109	20	-	19	< 1	< 5	< 5	-	-	-	-	-	-	-	.01	-	34	Se=8.9
09/18/75	-	1900	109	107	21	-	29	15	< 5	< 5	-	-	-	-	-	-	-	.01	-	34	Se=7.4
10/09/75	-	1170	83	81	31	-	0	27	0	85	-	-	-	-	-	-	78	0		58	Se 3.0
11/15/75	-	-	118	96	37	-	0	36	23	135	-	-	-	-	-	-	04	01		61	Se 7.0
01/16/76	-	-	95	10	1	141	95	29	10	0	0	-	-	-	347	-	01	0	-	03	Se=2.0, K 9.9
02/04/76	-	-	51	28	6	347	67	24	71	0	0	-	-	-	-	-	-	0	-	15	Se 2.0
02/04/76	-	-	37	23	4	449	66	26	27	5	4	-	-	-	-	-	03	0	-	.11	
03/13/76	-	-	29	12	4	468	18	5	18	10	6	-	-	-	72	-	02	0	-	15	
04/10/76	-	-	210	157	48	440	55	38	120	20	7	-	-	-	-	-	84	0	-	61	
05/05/76	6.4*	170	34	15	-	20	68	11	218	10	8	-	67	0	8	-	12	02	-	-	
05/05/76	7.8*	400	52	28	-	20	76	10	1070	10	10	-	83	0	73	-	10	01	-	-	
05/05/76	6.5*	340	90	39	-	100	450	8	295	-	-	-	70	0	285	-	08	01	-	-	
05/05/76	7.2*	325	42	18	-	20	20	12	235	14	< 5	-	4	0	12	-	08	.01	-	-	
05/05/76	6.5*	230	35	12	-	20	9	6	1420	10	5	-	53	0	9	-	.02	01	-	-	
05/09/76	-	-	191	142	40	175	< 10	112	46	< 10	8	-	-	-	-	-	29	02	-	53	
05/27/76	7.3	1650	105	82	29	10	20	23	10	10	4	-	247	0	-	-	2.05	46	-	51	
06/23/76	8.3	1150	126	70	28	100	10	26	< 10	10	< 4	-	131	0	-	-	1.81	0	-	49	
09/24/76	8.2	1650	101	105	60	363	90	25	13	20	5	49	244	0	-	7	09	0	-	1.00	F= 19
Inflow Flume (A)																					
03/10/76	8.3	350	28	15	5	745	60	< 5	60	10	9	-	-	-	79	-	.01	0	-	.24	
03/10/76	7.5	270	2	18	5	305	90	< 5	680	5	8	-	-	-	49	-	.01	.03	-	25	
03/10/76	7.7	230	0	16	5	82	98	< 5	230	0	8	-	-	-	32	-	03	03	-	26	
05/3[illegible]/76	[illegible]	760	140	52	8	5300	445	80	60	30	8	-	105	0	144		29	0	602	15	
05/3[illegible]/76	[illegible]	770	110	41	8	2400	206	71	40	10	7	-	102	0	316		17	0	528	.17	
05/3[illegible]/76	[illegible]	790	110	41	8	2200	185	72	53	< 10	8	-	104	0	340		.11	01	553	17	
05/3[illegible]/76	7.9	860	130	48	9	3400	255	88	67	210	9	-	131	0	372	-	.10	01	628	17	
05/[illegible]/76	7.9	830	130	40	8	3620	280	76	54	96	8	-	128	0	372	-	14	0	618	17	
05/[illegible]/76	7.9	840	120	45	8	2860	207	28	48	80	9	-	114	0	368	-	11	24	601	16	
05/[illegible]/76	-	-	125	43	8	3980	253	36	98	50	11	-	-	-	-	-	12	01	181	16	
06/2[illegible]/76	[illegible]	530	114	33	3	12500	555	65	88	10	4	-	98	0	272	-	1.11	0	489	07	
06/2[illegible]/76	[illegible]	670	94	28	4	4800	258	39	60	< 10	4	-	73	0	428	-	2.03	0	547	09	
06/[illegible]/76	[illegible]	730	255	70	3	22300	1425	110	127	10	4	-	63	0	572	-	76	12	955	04	
06/[illegible]/76	-	-	155	33	4	8440	540	49	41	10	4	-	-	-	-	-	-	-	-	03	
07/29/76	-	-	420	186	69	3660	700	41	41	27	10	-	-	-	-	-	-	-	-	20	
09/24/76	7.7	1900	161	150	80	6800	505	35	90	10	6	58	370	0	-	8	41	03	-	1.04	F= 17
Automatic Water Sampler(C) - Coalbank Coulee																					
04/04/[illegible]		-	14	23	2	-	10	10	5	5	-	-	-	-	-	-	-	25	-	08	Se=1.2
04/04/[illegible]	-	-	15	30	9	-	10	15	5	5	-	-	-	-	-	-	-	21	-	.31	Se=1.7
02/04/[illegible]	-	-	69	21	4	11	58	32	27	0	4	-	143	0	-	-	0	-	-	.11	Se= 1
05/27/76	7.9	360	99	23	5	3460	760	42	265	10	16	-	128	0	185	-	1.31	0	381		
05/27/76	8.1	420	90	23	5	3900	650	33	40	10	4	-	101	0	202	-	1.50	01	376	.13	
Automatic Water Sampler(B) - Spoils Runoff, Miller Coulee																					
04/14/[illegible]	-	-	68	36	8	-	40	1	5	5	-	-	-	-	-	-	-	1.12	-	20	
04/14/75	-	-	59	36	6	-	20	10	< 5	5	-	-	-	-	-	-	-	54		15	
04/14/75	-	-	92	52	9	-	22	10	5	5	-	-	-	-	-	-	-	.33	-	18	
07/09/75	-	-	115	42	6	-	410	2	< 5	5	-	-	-	-	-	-	-	01	-	.20	
07/09/75	-	-	78	32	4	-	406	1	5	5	-	-	-	-	-	-	-	.02	-	.10	
07/09/75	-	-	117	32	5	-	20	3	5	< 5	-	-	-	-	-	-	-	01	-	.11	
08/21/75	-	650	104	21	3	-	557	9	5	5	-	-	-	-	-	-	-	-	-	.07	
08/21/75	-	1000	112	28	6	-	665	2	< 5	< 5	-	-	-	-	-	-	-	.01	-	13	
03/29/76	8.2	440	-	146	8	15900	2345	118	12[illegible]	70	12	-	137	0	12.7	-	0	0	-	-	

**Selenium (Se) in µg/l; Flouride (F) and Potassium (K) in mg/l.

appear contradictory within a complete analysis; for example, ionic balances or the ratio between dissolved solids and specific conductance. It is felt, however, that the technique is adequate for establishing and monitoring baseline chemical characteristics. Specific conductance of surface waters at the mine ranged from a low of 230 µmhos/cm to 2100 µmhos/cm, both at the reservoir. In general, conductivity was lowest in Coalbank Coulee and highest at the inflow flume and the reservoir. Contribution of mine water to the inflow flume and reservoir may explain the higher concentration at these stations.

Calcium was the dominant cation at each monitoring station and, where sufficient data were available for evaluation, sulfate appeared to be the major anion. Sodium adsorption ratios for surface waters were usually less than 1.0.

Most trace elements were found in low concentrations at the surface water monitoring stations. Iron and manganese were the only consistent exceptions. Concentrations of these elements often exceeded acceptable limits (Table 8) at all three automatic water sampler stations and, for a few analyses, at the reservoir. Limited data suggested that manganese concentrations may have increased at Station B which monitors spoil runoff. Possible increases in sulfate, sodium, nitrate and iron at the inflow flume are suggested when the monthly data are compared.

With a few exceptions, surface waters at the Big Sky Mine are less mineralized than the ground water. Calcium and/or magnesium are generally the dominant cations in both water types and sulfate, except in the CW and UW wells, is the dominant anion. Iron and manganese are the major trace elements in both surface and ground water. These elements, together with sulfate, most frequently exceed acceptable limits for drinking water.

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Appendix A. Volumetric water percentages* at characteristic soil moisture tension ranges, Coalbank Coulee Research Area, Colstrip, Montana (1976).

Soil Sample Location	Depth of Sampling (cm)	Soil Moisture Tension, Atmospheres			
		0.0	0.1	0.3	15.0
		% H_2O	% H_2O	% H_2O	% $H_2O^{(+)}$
ALFALFA FIELD (Tube 149)	0-30.5	59.91	39.20	22.23	11.12
	30.5-61.0	59.55	41.37	16.98	8.49
	61.0-91.5	60.00	50.90	42.35	21.18
AVERAGE		59.82	43.82	27.18	13.59
DISTURBED RANGELAND (Tube 151)	0-30.5	63.42	45.74	20.19	10.10
	30.5-61.0	66.57	48.38	23.03	11.52
	61.0-91.5	61.64	43.16	16.35	8.18
AVERAGE		63.87	45.75	19.86	9.93
NATIVE RANGE (Tube 147)	0-30.5	73.91	58.97	36.84	18.42
	30.5-61.0	64.38	51.50	31.77	15.89
	61.0-91.5	55.32	40.67	23.55	11.78
AVERAGE		64.53	50.37	30.72	15.36

*All soils assumed to have a bulk density of approximately 1.5 g/cm^3.

*% H_2O (volumetric) = % H_2O (by weight) x Bulk Density.

(+)Equipment malfunction, all moisture percentages at 15 atms. assumed to be 1/2 (% H_2O) at 0.3 atms.

Appendix B. Volumetric Soil Water Contents, (Percent) Fluctuation at Neutron Tube Sites, Coalbank Coulee Research Area, Colstrip, Montana. 1975.

Location of Access Tubes	Increment Depth (cm)	Date 1-14	Increment Depth (cm)	1975 DATE (MONTH-DA 2-12	3-11	4-15	5-2	6-10	8-8	9-17	10-29	[illegible]
	0.0 - 22.5	43.55	0.0 - 22.5	48.80	19.64	03.87	07.15	35.20	13.49	14.50	20.15	27.10
	22.5 - 45.0	37.62	22.5 - 37.5	43.15	53.88	36.84	47.46	38.89	17.15	16.01	15.60	20.98
	45.0 - 75.0	24.76	37.5 - 52.5	30.52	41.20	38.36	48.30	37.16	16.74	16.36	14.43	20.67
NATIVE	75.0 - 105.0	32.47	52.5 - 67.5	27.57	29.76	36.07	47.31	36.79	23.20	22.20	17.76	29.34
	105.0 - 135.0	41.53	67.5 - 82.5	31.10	27.75	33.55	46.94	38.29	28.37	27.90	23.22	33.77
RANGE	135.0 - 165.0	38.39	82.5 - 105.0	35.14	31.01	29.57	47.21	40.69	34.64	36.06	28.83	43.55
	165.0 - 195.0	36.72	105.0 - 135.0	45.43	42.76	37.56	50.17	46.39	42.57	42.67	38.62	50.20
TUBE	195.0 - 225.0	43.00	135.0 - 165.0	42.52	47.01	41.59	51.56	41.79	37.53	35.43	35.71	40.14
	225.0 - 255.0	40.84	165.0 - 195.0	40.47	35.19	31.99	40.33	43.09	39.64	42.28	33.44	50.18
147	255.0 - 285.0	50.53	195.0 - 225.0	49.14	48.44	41.81	53.10	47.56	43.76	42.29	41.43	49.06
	285.0 - 315.0	55.22	225.0 - 255.0	48.67	50.31	45.07	56.33	50.62	46.23	46.38	39.83	57.03
	315.0 - 345.0	52.74	255.0 - 285.0	56.13	55.62	50.05	62.68	52.44	49.57	50.43	46.38	60.28
	345.0 - 375.0	52.98	285.0 - 315.0	58.28	57.97	49.62	62.68	52.94	50.72	50.94	46.38	62.17
	375.0 - 405.0	51.23	315.0 - 345.0	57.29	58.03	50.68	63.33	52.72	50.08	**	**	**
			345.0 - 375.0	57.72	57.93	50.01	62.55	52.44	50.21	**	**	**
			375.0 - 405.0	54.30	58.13	49.65	62.63	54.37	(a)	**	**	**
	0.0 - 22.5										22.49	39.41
SNIDER'S	22.5 - 37.5										15.87	20.44
	37.5 - 52.5										11.86	12.78
ALFALFA	52.5 - 67.5										08.15	10.15
	67.5 - 82.5										07.11	09.75
FIELD	82.5 - 105.0	*	*	*	*	*	*	*	*	*	07.33	10.03
	105.0 - 135.0										09.50	14.71
TUBE	135.0 - 165.0										09.45	13.24
	165.0 - 195.0										14.61	19.95
149	195.0 - 225.0										15.96	23.89
	225.0 - 255.0										19.14	28.88
	0.0 - 22.5	32.56	0.0 - 22.5	31.58	47.20	27.52	22.88	23.99	09.60	09.85	16.30	34.33
SNIDER'S	22.5 - 45.0	25.75	22.5 - 37.5	43.45	51.82	34.37	31.31	27.12	10.97	11.16	11.44	24.08
	45.0 - 75.0	21.18	37.5 - 52.5	40.05	39.87	35.24	33.25	34.54	12.43	11.13	10.24	20.48
ALFALFA	75.0 - 105.0	13.94	52.5 - 67.5	28.97	33.98	41.01	38.59	38.13	14.45	12.68	11.13	19.99
	105.0 - 135.0	12.61	67.5 - 82.5	28.65	34.67	42.57	40.66	42.10	16.51	12.96	11.63	19.12
FIELD	135.0 - 165.0	17.26	82.5 - 105.0	32.96	35.16	42.94	42.18	43.67	20.12	13.35	11.81	18.81
	165.0 - 195.0	30.28	105.0 - 135.0	30.54	32.08	38.98	41.43	52.23	34.71	19.33	14.80	25.80
TUBE	225.0 - 255.0	45.51	135.0 - 165.0	29.48	31.76	39.16	48.67	56.90	33.09	26.35	20.83	34.36
149	255.0 - 285.0	53.83	165.0 - 195.0	35.08	39.31	51.14	57.52	56.05	44.95	40.09	26.67	46.28
			195.0 - 225.0	41.88	49.95	56.34	55.73	52.70	48.24	46.25	42.04	56.92
			225.0 - 255.0	47.78	54.77	60.01	58.07	58.67	52.50	51.97	47.22	64.86
			255.0 - 285.0	53.87	57.68	64.48	61.29	-	-			
	0.0 - 22.5	27.21	0.0 - 22.5	30.67	27.59	07.17	05.17	22.51			16.60	30.80
SNIDER'S	22.5 - 45.0	26.57	22.5 - 37.5	46.07	53.67	30.32	27.36	27.40			13.15	24.46
	45.0 - 75.0	28.22	37.5 - 52.5	48.75	53.51	35.73	32.41	40.38			13.36	18.13
ALFALFA	75.0 - 105.0	21.35	52.5 - 67.5	39.66	48.76	43.77	41.30	40.55			13.46	18.51
	105.0 - 135.0	9.07	67.5 - 82.5	26.83	24.91	41.39	40.35	40.60			15.29	23.65
FIELD	135.0 - 165.0	15.08	82.5 - 105.0	26.06	26.55	39.12	39.62	42.20	*	*	20.30	30.91
	165.0 - 195.0	27.29	105.0 - 135.0	19.93	23.29	39.27	40.35	57.05			26.71	36.56
TUBE	195.0 - 225.0	36.73	135.0 - 165.0	13.95	16.31	31.43	43.81	56.25			20.54	35.30
			165.0 - 195.0	23.88	32.14	42.38	52.12	56.25			36.18	50.68
150			195.0 - 225.0	43.63	48.83	52.77	54.11	58.00			46.60	57.82
			225.0 - 255.0	50.39	54.37	54.57	54.46	57.50			47.65	56.26
	0.0 - 22.5	37.26	0.0 - 22.5	56.99	22.48	03.58	03.68	12.35	04.36	10.37	20.08	37.00
	22.5 - 45.0	43.71	22.5 - 37.5	51.06	53.96	38.42	33.67	25.45	18.10	21.32	24.55	37.76
	45.0 - 75.0	34.08	37.5 - 52.5	39.03	48.66	44.91	44.36	47.96	27.64	29.62	29.48	39.54
	75.0 - 105.0	40.30	52.5 - 67.5	34.88	39.25	41.81	44.13	47.84	33.70	36.48	34.57	47.66
	105.0 - 135.0	41.53	67.5 - 82.5	39.75	35.11	42.79	44.03	50.66	42.02	41.47	39.48	49.29
RANGELAND	135.0 - 165.0	42.75	82.5 - 105.0	40.88	39.78	43.74	45.32	51.67	42.57	42.16	40.50	50.18
	165.0 - 195.0	48.54	105.0 - 135.0	42.78	42.06	45.83	49.81	-	47.20	47.10	44.78	58.72
TUBE	195.0 - 225.0	52.03	135.0 - 165.0	44.93	43.12	53.38	56.26	57.73	48.06	43.08	37.11	68.75
	225.0 - 255.0	56.26	165.0 - 195.0	45.23	44.76	51.43	52.35	57.09	48.20	**	**	**
151	255.0 - 285.0	55.10	195.0 - 225.0	51.82	52.20	53.95	55.24	59.40	50.08	**	**	**
	285.0 - 315.0	56.38	225.0 - 255.0	51.62	51.16	52.08	53.92	57.85	48.80	**	**	**
			255.0 - 285.0	54.53	51.94	53.17	54.22	(a)	(a)	**	**	**
			285.0 - 315.0	53.93	68.85	71.16	72.19	(a)	(a)	**	**	**
			315.0 - 345.0	55.89	54.97	56.31	66.18	(a)	(a)	**	**	**

(a) - water *neutron tube nonfunctional **neutron tube change (read to shallower depth)

Appendix C. Volumetric Soil Water Content, (Percent) Fluctuation at 5 Neutron Tube Sites, Coalbank Coulee Research Area, Colstrip, Montana. 1976.

Location of Access Tubes	Increment Depth (cm)	1976 DATES (MONTH-DAY) 1-17	2-6	3-12	4-25	5-9	5-28	6-22	7-28	8-28	9-23	10-30
	0.0 - 22.5	42.66	44.09	41.87	41.74	35.15	29.38	32.54	11.97	07.18	09.36	19.10
	22.5 - 37.5	26.07	37.05	38.98	43.93	40.46	36.45	37.67	17.63	16.04	15.97	17.24
	37.5 - 52.5	22.03	35.33	36.54	40.05	39.54	37.57	35.78	17.88	16.69	16.75	14.47
NATIVE	52.5 - 67.5	27.72	34.89	35.41	38.12	39.41	37.49	34.19	19.27	16.76	16.88	15.13
	67.5 - 82.5	33.26	34.92	35.13	36.13	38.86	38.75	35.28	26.78	22.52	22.00	20.57
RANGE	82.5 - 105.0	43.17	37.23	39.42	38.25	40.36	40.92	36.97	34.46	32.79	31.74	28.76
	105.0 - 135.0	42.20	41.77	44.96	45.16	43.85	48.70	43.61	45.12	45.80	45.32	39.85
TUBE	135.0 - 165.0	39.04	38.46	41.14	42.63	41.29	45.95	42.01	41.81	43.61	42.82	37.70
	165.0 - 195.0	47.14	38.20	40.06	42.45	40.98	43.16	41.91	42.53	41.50	40.64	35.05
147	195.0 - 225.0	48.08	44.91	48.75	49.31	48.88	52.47	48.45	48.77	49.41	49.67	43.53
	225.0 - 255.0	54.24	46.60	49.39	54.17	51.35	53.36	51.38	51.10	49.66	48.30	42.61
	255.0 - 285.0	61.79	52.23	56.19	56.06	54.63	59.13	55.18	56.15	56.90	56.16	50.47
	285.0 - 315.0	69.00	60.07	64.19	61.96	61.46	66.97	62.57	61.86	59.67	59.09	54.99
	0.0 - 22.5	52.49	47.85	49.02	40.57	41.90	33.34	35.80	14.34	08.07	11.54	25.41
SNIDER'S	22.5 - 37.5	35.29	30.10	34.28	43.68	43.33	36.95	39.17	18.66	17.79	17.79	29.30
	37.5 - 52.5	23.79	18.99	23.30	34.64	36.87	30.20	31.66	15.91	15.83	15.56	16.97
ALFALFA	52.5 - 67.5	14.84	11.52	13.93	20.98	29.26	23.75	21.22	11.48	11.33	10.45	09.83
	67.5 - 82.5	10.32	09.64	09.90	12.53	27.53	22.39	18.41	12.07	09.90	08.88	07.85
FIELD	82.5 - 105.0	09.12	07.96	09.16	10.27	20.78	21.58	17.26	13.43	10.40	09.13	07.71
	105.0 - 135.0	11.56	11.11	12.62	13.11	13.58	16.14	18.08	16.34	14.09	12.96	10.29
TUBE	135.0 - 165.0	12.29	10.77	12.41	13.29	13.96	13.59	14.31	13.74	12.46	12.57	10.84
	165.0 - 195.0	17.56	16.40	18.09	19.82	21.26	20.58	19.93	20.47	18.90	18.19	15.43
148	195.0 - 225.0	18.91	17.84	20.79	22.75	24.75	23.71	24.29	22.75	20.50	19.65	16.91
	225.0 - 255.0	24.13	22.69	27.15	32.31	37.74	35.58	36.67	30.17	25.17	23.15	20.19
	0.0 - 22.5	35.55	37.44	41.12	30.90	27.63	13.61	18.59	04.13	03.36	03.91	14.89
SNIDER'S	22.5 - 37.5	24.90	24.23	27.98	31.22	31.03	21.17	23.92	09.60	08.98	09.17	19.94
	37.5 - 52.5	23.59	30.77	25.27	33.06	34.84	25.52	27.49	11.84	11.31	11.48	13.35
ALFALFA	52.5 - 67.5	23.84	34.13	28.22	37.00	39.78	30.27	31.43	13.75	12.76	13.31	11.93
	67.5 - 82.5	19.06	36.24	30.50	38.07	42.83	33.26	33.38	15.19	13.59	14.01	12.27
FIELD	82.5 - 105.0	16.41	36.29	29.39	35.85	43.07	34.30	31.92	15.68	13.98	13.73	12.31
	105.0 - 135.0	19.93	31.80	26.68	31.07	38.08	32.58	30.01	19.09	12.90	13.01	11.16
TUBE	135.0 - 165.0	25.27	33.22	29.57	34.44	40.37	37.21	34.97	27.04	16.82	15.36	13.39
	165.0 - 195.0	33.36	38.68	36.74	43.59	54.36	52.77	49.95	36.76	25.19	22.23	21.94
149	195.0 - 225.0	48.94	50.03	47.63	52.69	61.12	56.45	52.25	49.92	45.43	44.90	42.00
	225.0 - 255.0	55.85	56.59	53.97	56.83	64.27	58.82	54.06	55.00	55.91	56.72	50.47
	0.0 - 22.5	37.49	35.40	34.89	31.36	25.34	17.19	22.68	04.53	04.91	03.72	15.65
SNIDER'S	22.5 - 37.5	25.34	24.15	30.84	33.73	29.92	24.62	26.98	10.15	10.17	10.08	16.36
	37.5 - 52.5	25.04	21.08	33.19	38.81	38.22	32.82	34.08	13.92	14.80	13.15	13.33
ALFALFA	52.5 - 67.5	21.01	17.44	29.78	36.45	39.25	32.85	32.60	15.39	16.30	15.21	13.88
	67.5 - 82.5	19.74	19.67	29.27	35.26	37.89	34.67	32.51	17.83	16.84	15.18	14.21
FIELD	82.5 - 105.0	25.86	24.78	30.37	35.07	38.13	37.13	34.55	26.45	22.83	18.67	17.07
	105.0 - 135.0	33.13	30.20	32.39	39.20	42.73	44.66	43.37	37.15	31.02	26.30	23.51
TUBE	135.0 - 165.0	25.94	25.35	29.72	39.68	46.03	50.31	50.68	35.02	24.82	19.85	18.09
	165.0 - 195.0	43.79	43.48	44.83	50.67	58.37	56.31	55.08	39.21	35.39	35.24	31.38
150	195.0 - 225.0	54.15	50.86	50.28	55.82	57.20	59.28	57.41	51.96	56.70	52.19	46.66
	225.0 - 255.0	55.17	51.74	51.45	55.73	58.02	60.18	58.68	52.45	58.60	54.16	49.48
	0.0 - 22.5	38.04	47.11	36.06	38.87	35.95	26.03	37.58	01.50	05.51	04.97	09.48
DISTURBED	22.5 - 37.5	33.52	40.64	35.61	41.90	42.82	40.41	44.93	11.84	14.65	13.56	12.62
	37.5 - 52.5	35.84	40.53	37.99	42.08	44.29	44.59	45.49	24.34	23.19	23.06	26.71
RANGELAND	52.5 - 67.5	39.56	43.20	38.61	44.15	46.82	47.06	47.54	33.12	32.23	30.32	31.12
	67.5 - 82.5	44.93	47.33	41.79	46.46	48.88	50.52	49.21	40.05	46.05	41.03	39.13
TUBE	82.5 - 105.0	46.16	47.34	41.66	48.06	50.64	53.14	51.66	44.28	49.10	44.80	42.89
	105.0 - 135.0	50.09	53.87	48.60	58.59	60.79	62.66	61.22	47.38	53.04	46.63	43.66
151	135.0 - 165.0	54.99	75.27	61.77	70.77	77.46	79.88	77.81	73.96	40.43	34.67	31.97

Appendix D. Drillers Logs for Observation Wells at the Peabody Coal Company Big Sky Mine, Rosebud County, Montana.

Well Number	Date Drilled	Interval (ft.)	Lithic Description
11	7/09/75	0 - 17.0	sandy clay
		17.0 - 19.5	gravel
		19.5 - 21.0	gray shale
12	7/09/75	0 - 13.5	sandy clay
		13.5 - 24.0	gray shale
13	7/10/75	0 - 15.0	sandy clay
		15.0 - 18.5	sand and gravel
		18.5 - 22.0	gray shale
14	7/10/75	0 - 5.2	sandy clay
		5.2 - 12.0	sand
		12.0 - 27.0	dark sand and sandy clay
		27.0 - 27.7	coal (soft)
		27.7 - 31.0	gray shale
26	7/31/75	0 - 5.0	sandy clay
		5.0 - 15.0	sand with burn (dry)
		15.0 - 17.4	sand with burn (wet)
		17.4 - 38.5	sandstone
		38.5 - 40.0	gray shale
27	7/31/75	0 - 9.0	sandy clay
		9.0 - 13.7	sand with burn
		13.7 - 18.2	brown clay
		18.2 - 42.5	brown sandstone (wet)
		42.5 - 45.0	gray shale
28	8/01/75	0 - 15.0	sandy clay
		15.0 - 21.0	sand and gravel (wet)
		21.0 - 23.0	sandstone
29	8/01/75	0 - 2.5	sandy clay
		2.5 - 14.3	brown clay
		14.3 - 22.3	sand with burn (wet)
		22.3 - 23.3	soft sandstone
30	8/02/75	0 - 4.0	sandy clay
		4.0 - 10.0	sand
		10.0 - 18.0	sand with burn (wet)
		18.0 - 20.2	brown shale

Appendix D. (cont.)

Well Number	Date Drilled	Interval (ft.)	Lithic Description
31	8/02/75	0 - 6.0	sandy clay
		6.0 - 8.0	sand
		8.0 - 30.2	brown sandstone (dry)
		30.2 - 36.2	brown sandstone (wet)
		36.2 - 39.2	brown shale
		39.2 - 40.0	gray shale
32	8/03/75	0 - 5.3	sandy clay
		5.3 - 39.6	sand with burn (dry)
		39.6 - 62.0	brown sandstone (dry)
		62.0 - 77.7	brown sandstone (wet)
		77.7 - 79.0	gray shale
63	9/24/75	0 - 4.2	sandy shale
		4.2 - 42.3	sand
		42.3 - 102.8	sandstone
		102.8 - 103.0	coal
		103.0 - 129.6	sandy shale
		129.6 - 135.5	sandstone
		135.5 - 138.3	sandy shale
		138.3 - 151.5	sandstone
		151.5 - 151.7	coal
		151.7 - 152.0	shale
		152.0 - 177.4	coal
		177.4 - 180.0	shale (H_2O)
64	9/29/75	0 - 4.8	shale
		4.8 - 29.0	sand
		29.0 - 31.0	sandy shale
		31.0 - 56.0	sandstone
		56.0 - 58.0	shale
		58.0 - 58.4	coal
		58.4 - 58.8	shale
		56.8 - 61.0	coal (H_2O)
65	9/30/75	0 - 6.7	sandy shale
		6.7 - 9.2	clay
		9.2 - 37.3	sandy shale
		37.3 - 41.5	shale
		41.5 - 45.0	coal
		45.0 - 47.0	? (H_2O)

Appendix D. (cont.)

Well Number	Date Drilled	Interval (ft.)	Lithic Description
66	10/03/75	0 - 2.0	sand
		2.0 - 16.0	fill
		16.0 - 21.0	sandstone
		21.0 - 25.0	coal (smutty)
		25.0 - 39.0	coal
67	10/06/75	0 - 5.6	sandy shale
		5.6 - 23.4	sand and gravel
		23.4 - 65.5	sandstone
		65.5 - 70.2	shale
		70.2 - 73.2	sandstone
		73.2 - 90.9	sandy shale
		90.9 - 95.8	sandstone
		95.8 - 123.9	sandy shale
		123.9 - 150.6	coal
		150.6 - 160.0	shale
68	10/07/75	0 - 5.0	shale
		5.0 - 17.0	sand
		17.0 - 25.0	sandstone
		25.0 - 25.4	shale
		25.4 - 50.0	coal
69	10/08/75	0 - 23.0	sand
		23.0 - 24.0	hard rock
		24.0 - 30.0	shale
		30.0 - 80.0	sandstone
70	10/09/75	0 - 2.2	red sandstone
		2.2 - 10.1	sandy shale
		10.1 - 12.0	gravel (H_2O)
71	10/10/75	0 - 30.5	fill
		30.5 - 45.0	coal (smutty)
		45.0 - 69.6	sandy shale
		69.6 - 75.0	sandstone
72	--	0 - 1.1	shale
		1.1 - 1.5	coal
		1.5 - 25.0	sandy shale
73	10/23/75	0 - 25.5	sandy shale
		25.5 - 120.3	sandstone
		120.3 - 130.2	shale
		130.2 - 135.7	sandstone
		135.7 - 144.6	sandy shale
		144.6 - 175.0	siltstone

Appendix . Depth to water measurements for observation wells at the Peabody Coal Company Big Sky Mine, Rosebud County, Montana

Well Number	Depth[1] (ft)	Ground Elevation(ft, ASL)	Height of Casing(ft)	Casing Diameter (inches)	Monitored Zone[3]	1974 October Date	October DTW[2]	November Date	November DTW	December Date	December DTW
1	36.5	--	2.0	3	Fort Union	02	33.7	06	34.2	06	34.2
2	90.9	--	2.4	4	Fort Union	02	26.3	06	26.0	06	26.5
3	63.3	--	2.4	4	Fort Union	02	26.7	06	26.3	06	26.5
4	24.0	--	2.2	4	Fort Union	02	12.6	06	12.8	06	13.0
5	109.5	--	2.3	4	Fort Union	02	24.7	06	25.0	06	25.1
6	33.5	--	1.9	4	Fort Union	02	23.9	06	24.4	06	24.6
11	20.6	3143.12	1.4	4	Alluvium						
12	22.0	3148.32	2.5	4	Fort Union						
13	18.7	3158.37	1.6	4	Alluvium						
14	28.6	3159.48	2.2	4	Fort Union						
26	39.5	3203.11	2.8	4	Alluvium						
27	43.9	3194.97	1.8	4	Alluvium						
28	22.4	3186.69	1.2	4	Alluvium						
29	23.2	3178.35	1.7	4	Alluvium						
30	19.6	3168.49	1.4	4	Alluvium						
31	39.8	3207.96	2.0	4	Fort Union						
32	79.5	3270.57	1.8	4	Fort Union						
63	176.0	--	.6	4	Rosebud Coal						
64	60.5	--	1.1	4	Rosebud Coal						
65	46.3	--	.8	4	Rosebud Coal						
66	38.5	--	.7	4	Rosebud Coal						
67	154.0	--	.7	4	Rosebud Coal						
68	46.4	--	1.3	4	Rosebud Coal						
69	77.2	--	1.8	4	Fort Union						
70	11.7	--	1.5	4	Alluvium						
71	74.5	--	1.2	4	Fort Union						
72	22.0	--	1.3	4	Fort Union						
73	169.4	--	1.3	4	Fort Union						
UW	31.2	--	1.9	4	Fort Union	02	22.2	06	22.7	06	22.6
LW	50.7	--	1.3	4	Fort Union	02	19.2	06	19.6	06	19.8
CW	76.2	--	1.6	4	Fort Union	02	28.6	06	34.4	06	35.0
CE	56.9	--	2.8	4	Fort Union	02	40.0	06	38.7	06	39.5

(1) Measured 11/11-15/76

(2) Depth to water (DTW) Note: All depths relative to ground surface

(3) Extent of perforations in well casings uncertain. Drillers instructions were to drill wells in Miller Coulee and lower Coalbank Coulee watersheds into saturated zone and then perforate casing in this zone. Wells in upper Coalbank Coulee watersned were installed to monitor water levels in the Rosebud coal.

Appendix E. (cont.) Depth to water measurements for observation wells at the Peabody Coal Company Big Sky Mine, Rosebud County, Montana.

	1975																			
Well	January		February		March		April		May		June		July		August		September		October		November	
Number	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW
1	08	33.2	10	28.1	16	32.2	14	34.9	02	32.8	03	32.1	15	31.9	10	31.7	18	31.8	09	31.7	14	31.3
2	08	25.6	10	23.5	16	25.4	14	24.3	02	22.2	03	21.7	15	21.1	10	21.5	18	22.0	09	22.3	14	21.7
3	08	26.0	10	25.0	16	24.6	14	24.7	02	22.8	03	22.1	15	21.4	10	21.3	18	22.2	09	22.4	14	21.6
4	08	13.0	10	13.0	16	13.5	14	13.0	02	12.8	03	12.4	15	11.4	10	11.7	18	11.6	09	11.5	14	11.3
5	08	25.1	10	19.8	16	24.3	14	23.9	02	23.9	03	23.4	15	23.6	10	23.6	18	23.7	09	23.8	14	23.8
6	08	23.8	10	23.8	16	23.3	14	23.9	02	24.0	03	23.7	15	23.6	10	23.7	18	23.7	09	23.7	14	23.6
11																	24	12.5	09	12.5	15	12.4
12															10	13.0	24	12.4	09	12.4	15	12.5
13															10	9.0	24	8.9	09	8.8	15	8.4
14															10	18.2	24	17.4	09	17.2	15	17.5
26																	24	23.6	09	23.5	14	23.5
27																	24	23.2	09	23.2	14	23.2
28																	24	19.1	09	18.9	14	19.0
29																	24	19.1	09	19.0	14	19.0
30																	24	15.5	09	15.4	14	15.0
31																			09	35.2	14	35.1
32																			09	68.2	14	68.1
63																					15	110.6
64																					15	46.2
65																					15	37.5
66																					14	28.6
67																					14	72.5
68																					14	24.5
69																					14	63.8
70																					15	5.8
71																					14	dry
72																					14	8.5
73																					15	123.1
UW	08	22.3	10	22.2	16	--	14	23.7	03	23.4	03	22.1	15	24.5	10	24.2	18	22.3	09	22.5	14	22.4
LW	08	19.3	10	18.9	16	18.4	14	19.0	05	19.1	03	19.0	15	19.4	10	19.2	--	--	--	--	--	--
CW	08	28.2	10	28.7	16	26.6	14	27.5	05	26.5	03	28.2	15	28.6	10	29.1	17	29.3	09	29.2	14	29.0
CE	08	39.0	10	37.1	16	35.9	14	36.1	05	36.8	03	36.4	15	38.0	10	38.6	17	40.0	09	40.2	14	39.8

Appendix E (cont.). Depth to water measurements for observation wells at the Peabody Coal Company Big Sky Mine, Rosebud County, Montana.

	1976																					
Well	January		March		April		May		May		June		July		August		September		October		November	
Number	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW	Date	DTW
1	16	30.9	13	30.6	10	30.7	10	30.4	27	30.2	21	30.4	29	29.9	27	29.8	23	29.6	30	29.6	13	29.2
2	16	21.0	13	19.2	10	19.0	10	17.4	27	17.3	21	16.6	29	16.6	27	17.3	23	16.7	30	16.3	13	15.6
3	16	21.3	13	19.8	10	19.2	10	17.5	27	17.2	21	16.8	29	16.9	27	17.6	23	17.2	30	18.4	13	16.0
4	16	11.7	13	11.6	10	11.6	10	11.6	27	11.3	21	11.7	29	11.4	27	11.3	23	11.4	30	11.0	13	11.1
5	16	23.3	13	23.4	10	23.2	10	22.9	27	22.7	21	22.5	29	22.4	27	22.4	23	22.3	30	22.0	13	22.0
6	16	23.5	13	23.4	10	23.5	10	23.5	27	23.2	21	23.3	29	23.3	27	23.3	23	23.2	30	23.2	13	23.0
11	16	12.2	13	11.9	10	12.0	10	11.5	28	12.0	21	11.6	29	12.2	27	12.5	23	12.4	30	12.1	11	12.1
12	16	12.5	13	12.2	10	12.2	10	12.1	28	12.9	21	11.1	29	12.2	27	12.7	23	12.8	30	13.1	11	12.6
13	16	7.9	13	7.8	10	7.4	10	6.8	28	7.4	21	6.9	29	8.2	27	8.8	23	8.9	30	8.4	11	8.4
14	17	17.0	13	16.7	10	16.8	10	16.8	28	16.8	21	16.8	29	17.3	27	17.5	23	17.3	30	16.9	11	17.0
26	17	23.5	13	23.6	10	23.2	10	23.2	28	23.2	21	23.2	30	23.1	27	23.1	23	23.0	30	23.1	14	23.0
27	17	23.0	13	23.1	10	23.0	10	22.9	28	22.9	21	22.9	30	22.9	27	22.9	23	22.9	30	22.9	14	22.9
28	17	18.7	13	18.7	10	18.7	10	18.7	28	18.7	21	18.7	30	18.9	27	18.9	23	18.9	30	18.9	12	18.9
29	17	18.7	13	18.9	10	18.5	10	19.0	28	18.6	21	18.3	30	18.8	27	19.0	23	18.9	30	18.8	12	18.8
30	17	14.5	13	14.0	10	14.4	10	13.9	28	14.2	21	13.8	30	15.0	27	15.5	23	15.7	30	15.1	12	15.0
31	17	34.7	13	34.6	10	34.7	10	34.5	28	34.5	21	34.6	30	34.6	27	34.6	23	34.5	30	34.5	11	34.5
32	17	67.4	13	67.4	10	67.6	10	67.4	28	67.4	21	67.5	30	67.5	27	67.5	23	67.5	30	67.4	11	67.5
63	17	109.9	13	108.3	10	110.2	10	110.3	28	110.3	23	110.5	30	110.7	27	110.8	23	110.9	31	110.8	15	110.8
64	17	46.7	13	46.8	10	46.0	10	46.2	28	46.3	23	47.0	30	47.1	27	47.2	23	47.4	31	47.3	15	47.4
65	17	37.1	13	37.2	10	37.2	10	37.3	28	37.4	23	37.4	30	37.5	27	37.7	23	37.6	31	37.5	15	37.6
66	17	28.6	13	29.1	10	29.4	10	29.1	28	29.2	21	29.0	30	29.3	27	29.4	23	29.3	31	29.3	15	29.3
67	17	64.4	13	63.8	10	63.8	10	63.6	28	63.5	21	63.5	30	63.4	27	63.3	23	63.3	31	63.2	15	63.1
68	17	24.1	13	24.8	10	24.1	10	24.0	28	24.0	21	23.9	30	24.1	27	24.3	23	24.5	31	24.1	14	24.0
69	17	63.0	13	59.8	10	63.0	10	62.7	28	62.7	21	62.7	30	62.7	27	62.7	23	62.6	31	62.6	14	62.4
70	16	5.5	13	4.4	10	4.5	10	3.9	28	4.1	21	3.6	29	4.9	27	5.7	23	6.0	30	6.2	11	6.2
71	17	dry	13	dry	10	dry	10	dry	28	dry	21	dry	30	dry	27	dry	23	dry	31	dry	15	dry
72	17	8.2	13	8.8	10	8.9	10	8.6	28	9.2	21	8.5	30	9.7	27	10.0	23	9.6	31	8.9	15	9.42
73	17	118.3	13	118.4	10	121.8	10	121.5	28	121.7	23	121.9	30	122.0	27	122.0	23	121.9	31	121.9	15	121.7
UW	18	21.7	13	22.2	10	22.5	--	--	--	--	--	--	--	--	--	--	23	23.7	31	24.1	13	24.2
LW	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	31	21.2	13	21.4
CW	18	28.0	13	28.9	10	40.4	10	39.7	28	31.0	23	32.3	30	40.0	27	42.7	23	40.3	31	46.1	13	44.0
CE	18	39.5	13	40.0	10	41.0	10	40.4	28	41.6	23	42.7	30	43.5	27	43.9	23	47.1	31	50.9	13	51.1

Appendix F. Miller Coulee Hydrologic Data

The hydrologic data collection program for Miller Coulee, discussed in this appendix, was begun prior to the Coalbank Coulee studies. These data provide a reasonably continuous record of mining and post-mining water level fluctuations in Miller Coulee.

Observation wells 1, 2, 3, 4, 5 and 6 were installed early in the program to monitor possible water level changes in the near surface material downslope from reclaimed spoils (Figure 1). The hydrographs for these wells are shown in Figure F-1. Each of the wells have apparently undergone recharge since the spring of 1975. Reasons for this are not well understood. It may be related to the developing reservoir or to the possibility that the reclaimed spoils have retained precipitation resulting in the formation of a ground-water mound.

Observation wells CW, CE, UW and LW (Figure 1) provide data on the effects of the approaching highwall on the shallow ground-water regime directly northwest of the present mining activity in Miller Coulee. The most illustrative responses are shown for the CW and CE wells in Figure F-2. These wells located close to the highwall have both shown a significant decrease in levels since the spring of 1975. This strongly suggests that mining activities have effectively drained ground water from the adjacent upslope sediments.

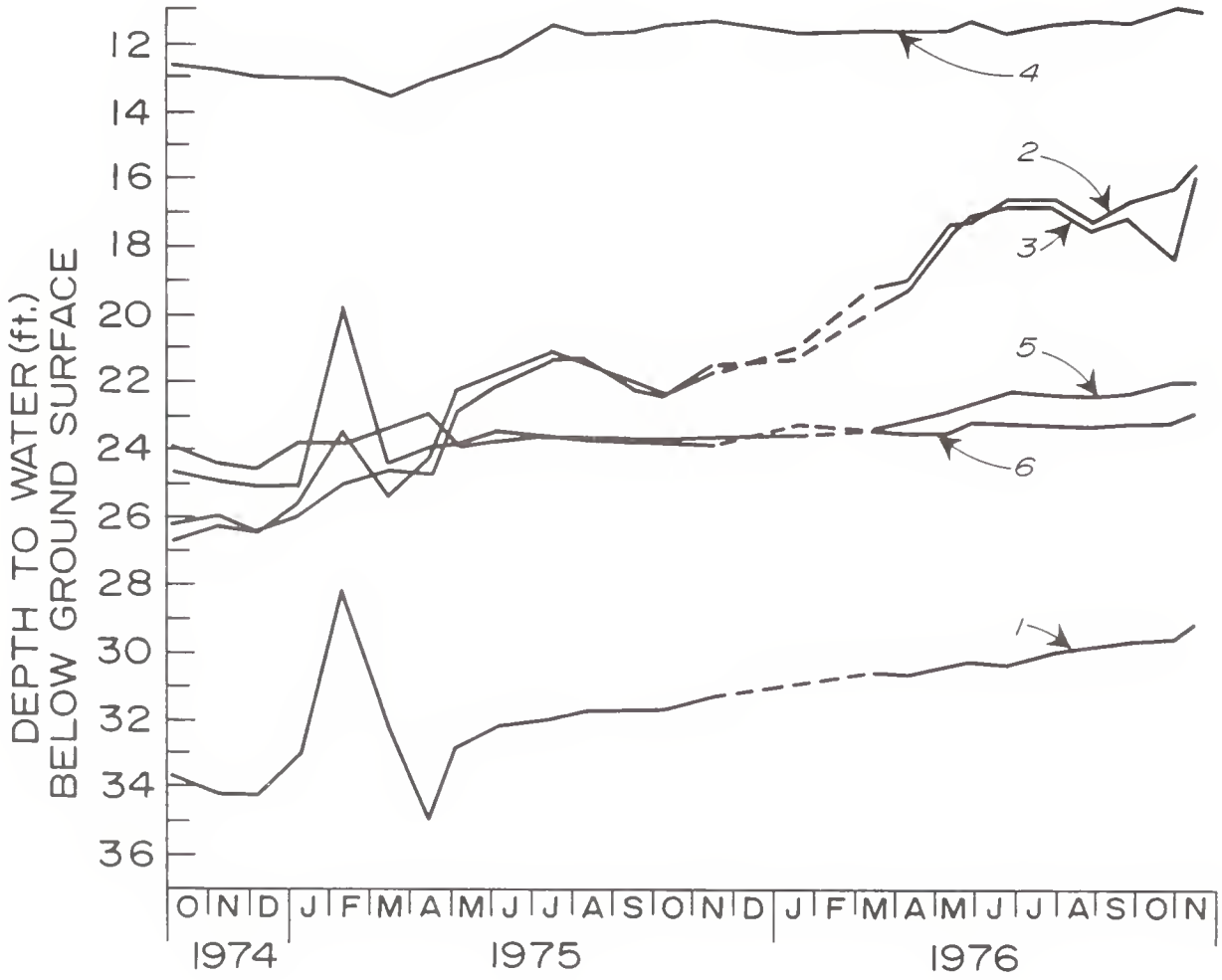

Figure F-1. Water level fluctuations in observation wells 1-6 in Miller Coulee watershed.

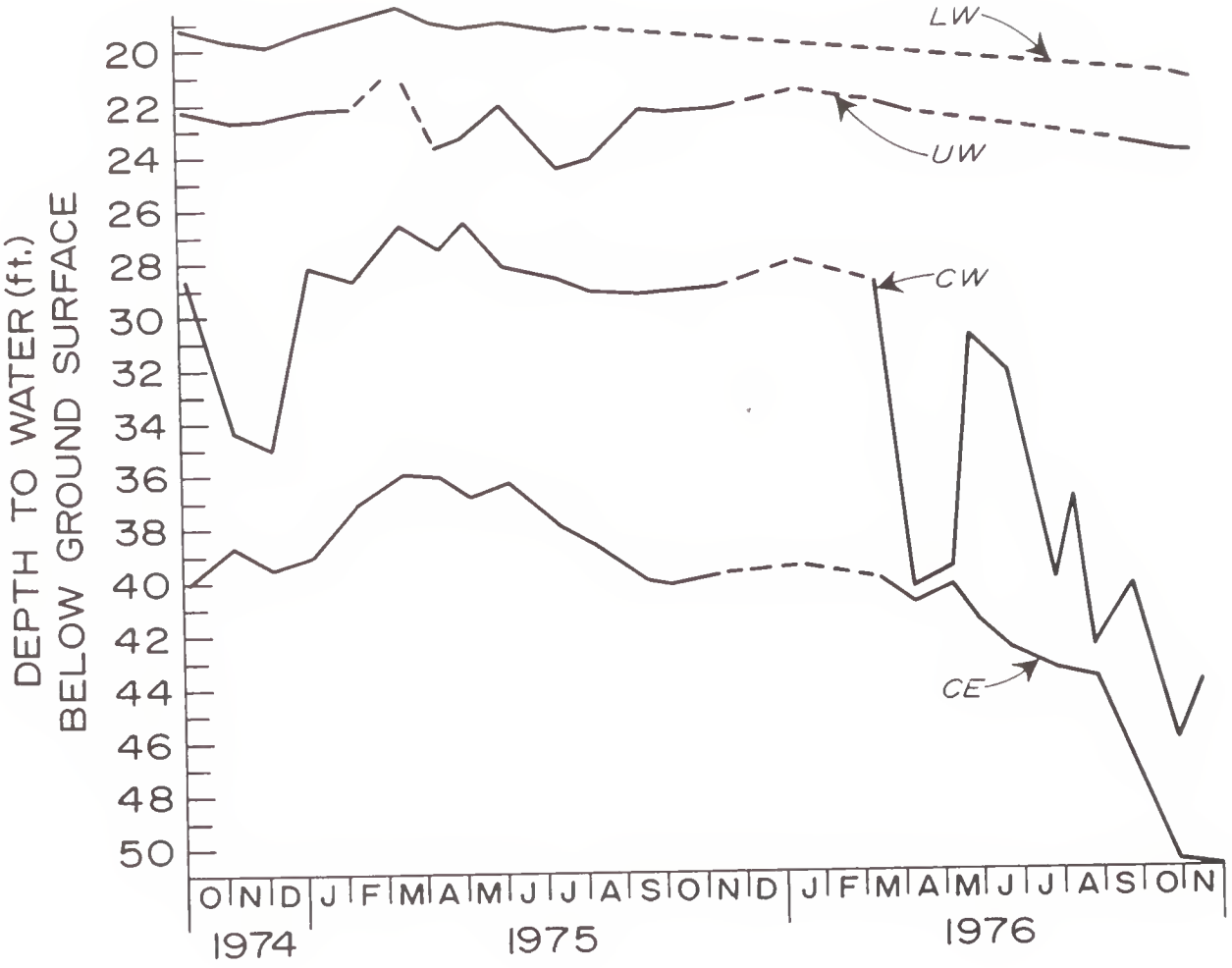

Figure F-2. Water level fluctuations in observation wells CE, CW, UW, and LW in Miller Coulee.